WINTER WEATHER TYPES OF THE EASTERN NORTH PACIFIC AND ADJACENT COASTAL AND ISLAND AREAS

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PART I

INTRODUCTION

In the preliminary considerations of this problem, the idea back of the whole investigation was to afford the U. S. Naval Service with a detailed study of the weather conditions of the eastern part of the North Pacific Ocean from which a logical solution of the weather in this area could be obtained from the available land reports. In case of a war (and it is upon these assumptions that the plans of the Navy must be formulated) it is assumed that the intricate system or network of reports over the continent of North America, particularly the United States and territories and island possessions will be available to the Navy; but the ship reports over the North Pacific will be reduced to a negligible figure. But it is just at this time that the weather situation over the North Pacific will be a vital factor in the operations of the United States Navy. "Forewarned is Forearmed" ---and all the advance information that is available to the Naval Forces will be decisive factor in the success of a mission, likewise if this information is not available to the enemy it will deter him in carrying out his mission. With this idea in mind it was decided to carry out a study of the weather conditions of the eastern part of the North Pacific.

In 1938 the U. S. Department of Agriculture issued a most complete and comprehensive Weather Bureau Publication entitled, "Atlas of the Climatic Conditions of the Oceans". This publication was issued to the U.S. Naval Service and is the summary of some five and one-half million ship weather observations over a period of fifty years. This publication together with the Pilot Charts published by the Hydrographic Office gives the most complete and accurate summary of average weather conditions that can be obtained, however, these give only average conditions for any one particular month. Any attempt to deduce average weather conditions by months from individual daily maps would be merely supplemental to what has already been done. Furthermore, knowing the average weather conditions for the month is of little help in solving the individual synoptic situation for any particular day. Obviously, the need is for some means of completing the weather map over the wide expanses of the ocean without direct observations. The only hope in such a dilemma is to find some way to fill in this blank space from what we have: the continental and island observations.

Several Navy Aerologists, Lieuts. W. E. Gist, R. O. Minter, and E. W. Stephens and Lieut. Comdr. W. M. Lockhart have made studies of the weather in this area, made classifications of the types and published their results, however, none of these is comprehensive enough for the present purpose since they are either made for a particular route or a particular month.

At the outset it was felt that there might be some correlation between the weather types over the continent and those over the Pacific. Naturally if such a correlation exists, it would be a fairly simple matter to complete the ocean areas since the continental weather would be known. With this idea in mind the following weather maps were studied for clues that would lead to definite types:

(1) M.I.T. Official Northern Hemisphere Surface Maps, 1936, 1937, 1938
(2) M.I.T. Official United States and adjacent oceans Surface weather maps, 1937, 1938, 1939
(3) Cal Tech. Official United States and adjacent Pacific area surface weather maps, 1938, 1939, 1940
(4) Deutsche Seewarte Northern Hemisphere Synoptic Maps for the Polar Year 1932-1933

It was discovered from a close study of the above maps that innumerable type classifications could be catalogued; in other words, the continental interior surface weather distribution has no coordination with the distribution of centers of action or fronts in the Pacific area. The only part of the continent that bears any relation to the oceanic area is a narrow coastal strip varying between one and three hundred miles from the coast. The reasons for this lack of coordination are explained in further detail in the Air Mass Section which follows.

Since most of the maritime air from the Pacific goes aloft upon striking the mountains along the west coast, it was felt that there might be some clue in the upper air maps of the continent to the wind or pressure distributions at the surface in the Pacific. Consequently, the daily 3 kilometer pressure maps for several months were compared with the corresponding surface maps, but this proved unsatisfactory chiefly because the region of most intense activity, namely, that north of the U.S.-Canadian border is almost devoid of pilot balloon stations and boasts only two aerological stations: Juneau and Fairbanks. The writers believe, however, that a denser network of aerological and pilot balloon stations in Canada and Alaska enabling the construction of more complete and accurate upper level maps will be productive in the effort to link Pacific weather with Continental. Along this channel it is pertinent to note that Rossby (1939) has found a close correlation between the Zonal Circulation Intensity and the Longitude of the Aleutian Low as determined by Five Day Mean Pressure Charts. It may be that the zonal circulation in the 3 kilometer level over the western part of the continent bears some immediate relation to the position of the Aleutian Low. This is suggested as a subject for further research.

In the light of the foregoing investigations it was finally decided that a type classification of the weather conditions for the winter months of the Eastern North Pacific and adjacent coastal and island areas would be the most fruitful line of attack and would result in the greatest practical value at present for any attempt at deducing the synoptic situation in the absence of direct observations within the ocean area itself. A detailed description of the types chosen with their prevalance, persistance, trend, and a statistical study of the associated weather in each type follows.

PART II

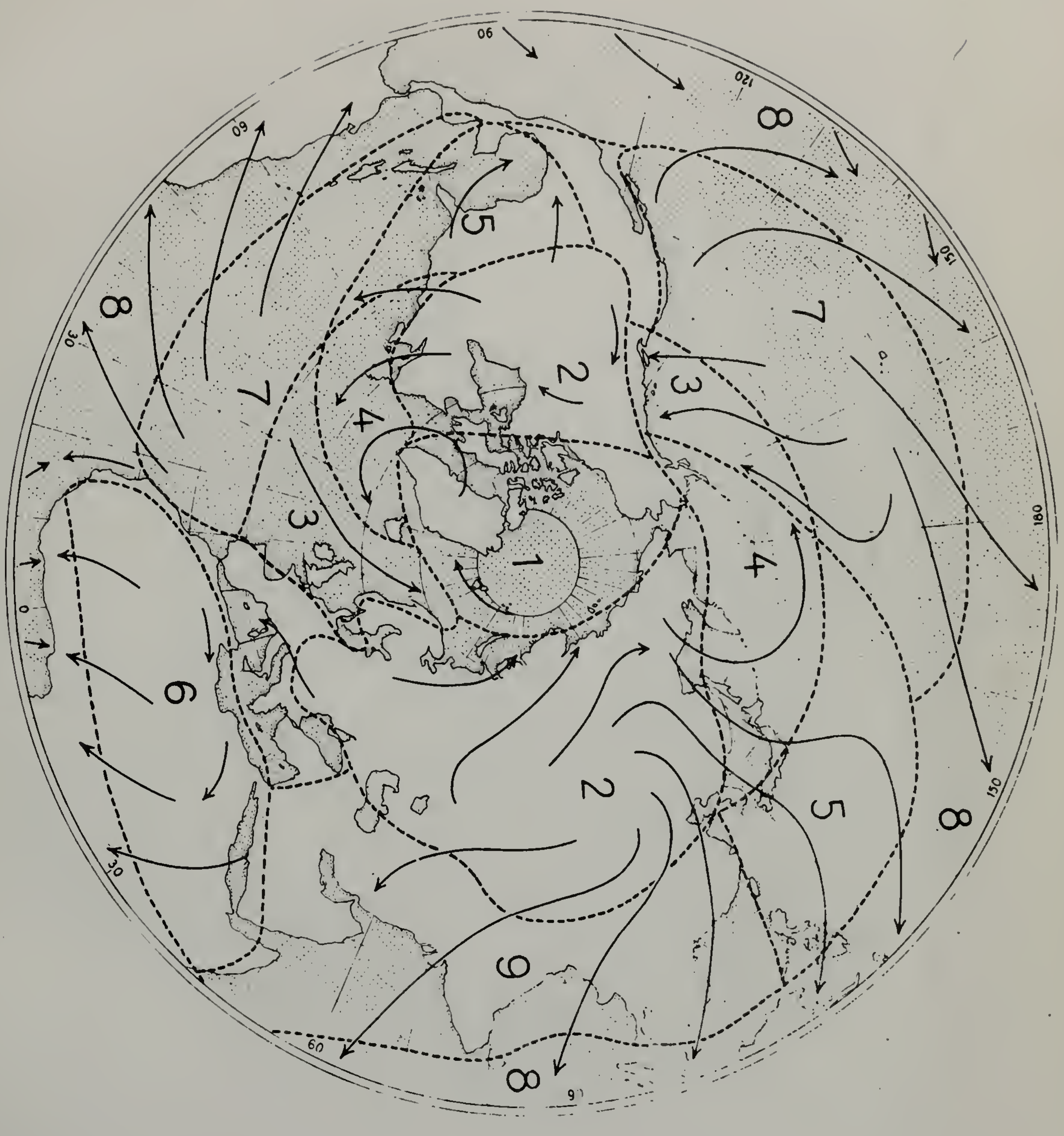
AIR MASSES OF THE NORTH PACIFIC

Before proceeding to a detailed study of the types selected and their attendent weather it will be appropriate first to set down briefly the general pattern of the air mass distribution of the North Pacific.

The air masses which affect the weather of the North Pacific are:

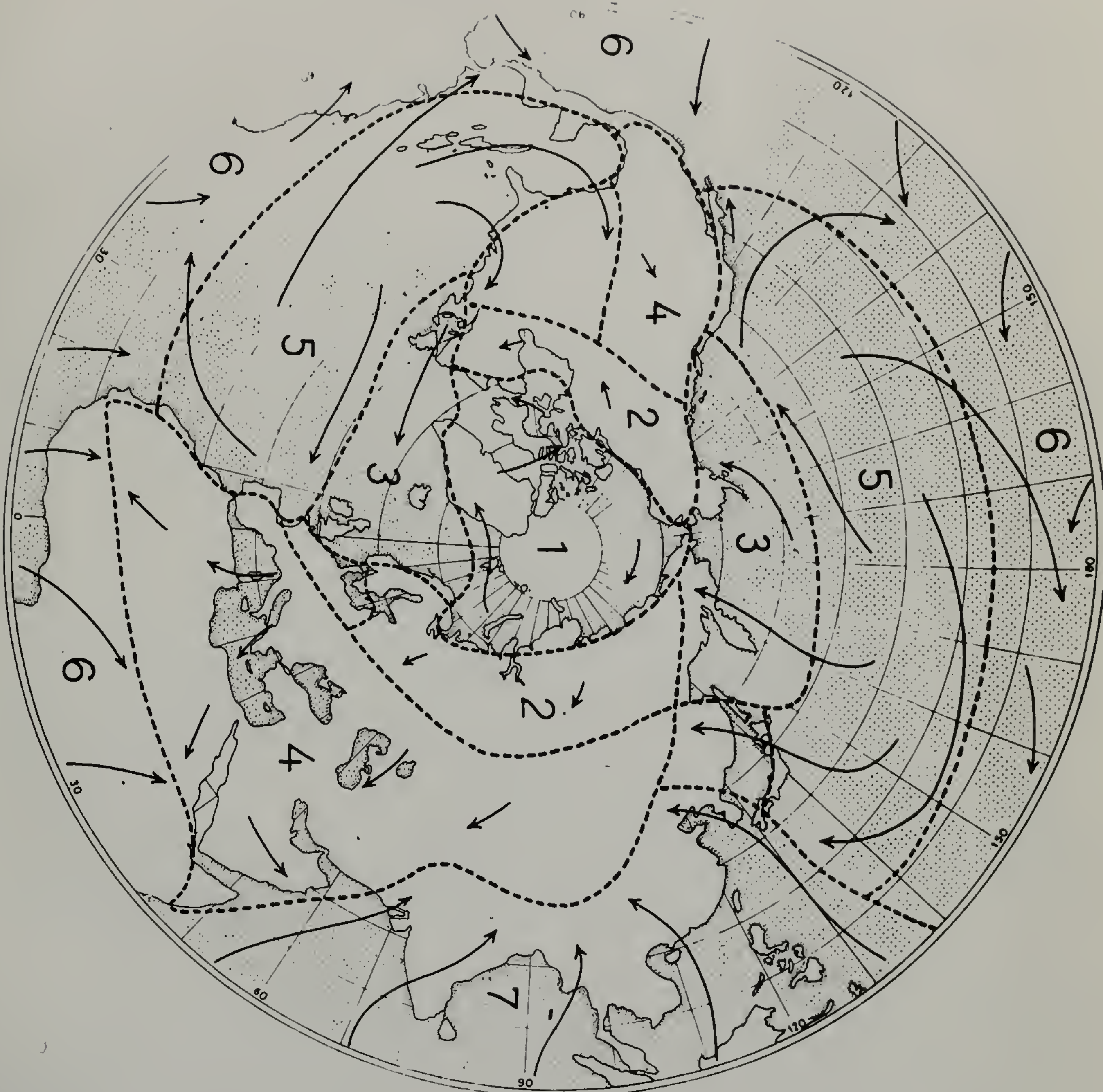
(1) Polar Continental--Siberian
(2) Polar Continental--Canadian
(3) Arctic
(4) Polar Pacific
(5) Tropical Pacific

Since the first three types are cold and dry, the weather associated with them will be characterized by clear skies and good visibility; however, a trajectory out of Siberia or the Arctic regions which requires a long passage over the warmer waters of the Pacific causes a transition to Polar Pacific air. This type is near saturation at the surface and has a decreasing equivalent potential temperature with altitude which makes it convectively unstable. Tropical Pacific air originates in the subtropical high pressure cell or cells of the horse latitudes. It is a deep, moist, warm air mass and usually has a very constant or increasing equivalent potential temperature with altitude.



Winter Source Regions

PLATE I



Summer Source Regions

PLATE 2

AIR MASSES IN WINTER

In the winter rapid radiation from the continents causes cooling of the overlying air and the regions become vast source regions of cold, dry air. In these source regions advection is small and the air is forced to take on the characteristics of the earth's surface. This cold, dry air is known as Polar Continental (Pc) air. It is formed in Zones numbered 2, plate 1, (Canada and Siberia).

As the cold dry air flows out from Siberia over the warmer water of the Western North Pacific it continuously picks up moisture, takes on the temperature of the water at the surface and becomes subject to deep convection and the development of convective instability. By the time it has travelled a few hundred miles to the east and southeast, therefore, it has changed its characteristics to a deep, cold, moist type of air. This is the type of air overlying the North Pacific most of the time and is known as Polar Pacific (Pp) air. The zone of transition and consequently of the formation of Pp air is Zone 4, Plate 1. (Zone 4 of the Atlantic is known as the Polar Atlantic (Pa) source region. When Pp air travels southward over much warmer water, the convective instability results in the production of heavy convectional showers.

In the lower latitudes between 10° and 30° N. huge cells of subsiding and diverging air (Zones 5, Plate 1) are present over the warm waters of the oceans. These are the source regions of Tropical Maritime (Tm) air which in the Pacific is known as Tropical Pacific (Tp) air. This air is warm and moisture laden and when transported northward over cooler waters of the North Pacific becomes cooled to the dew point and produces widespread fog or low stratus clouds.

Arctic (A) air is formed in the far northern ice and snow fields of the Arctic Ocean, Zone 1, Plate 1. Because of the nature of the region Arctic air is very little different from Polar Continental air in winter so it is often very difficult to distinguish between them. Furthermore, almost all Arctic air enters the Pacific through the Bering Strait because the high mountains of Alaska prevent its passage over the continent into the Pacific, hence, it soon undergoes transition to Polar Pacific air. In summer, however, Arctic air is the principal cold air mass affecting the North Pacific.

AIR MASSES IN SUMMER

In the summer there is not nearly so much difference in the characteristics of the air masses. In fact there are no well defined sources of Pc air in summer since the continents are regions of strong heating from solar radiation. The Arctic regions, however, are still a good source of cold air since they are always snow and ice covered.

The ocean is fairly homogeneous and the annual variation of the temperature is small so that Zone 3, plate 2 is still a good source region for Pp air. Zones 2, plate 2, are source regions for Pc air, but as stated above are very small and ill defined as source regions. On the other hand, the source regions of Tp air, Zone 5, plate 2, is much more extensive both northward and westward. The principal air mass of the Pacific in summer is this type, Tp.

PRINCIPAL AIR CURRENTS OF THE NORTH PACIFIC--WINTER

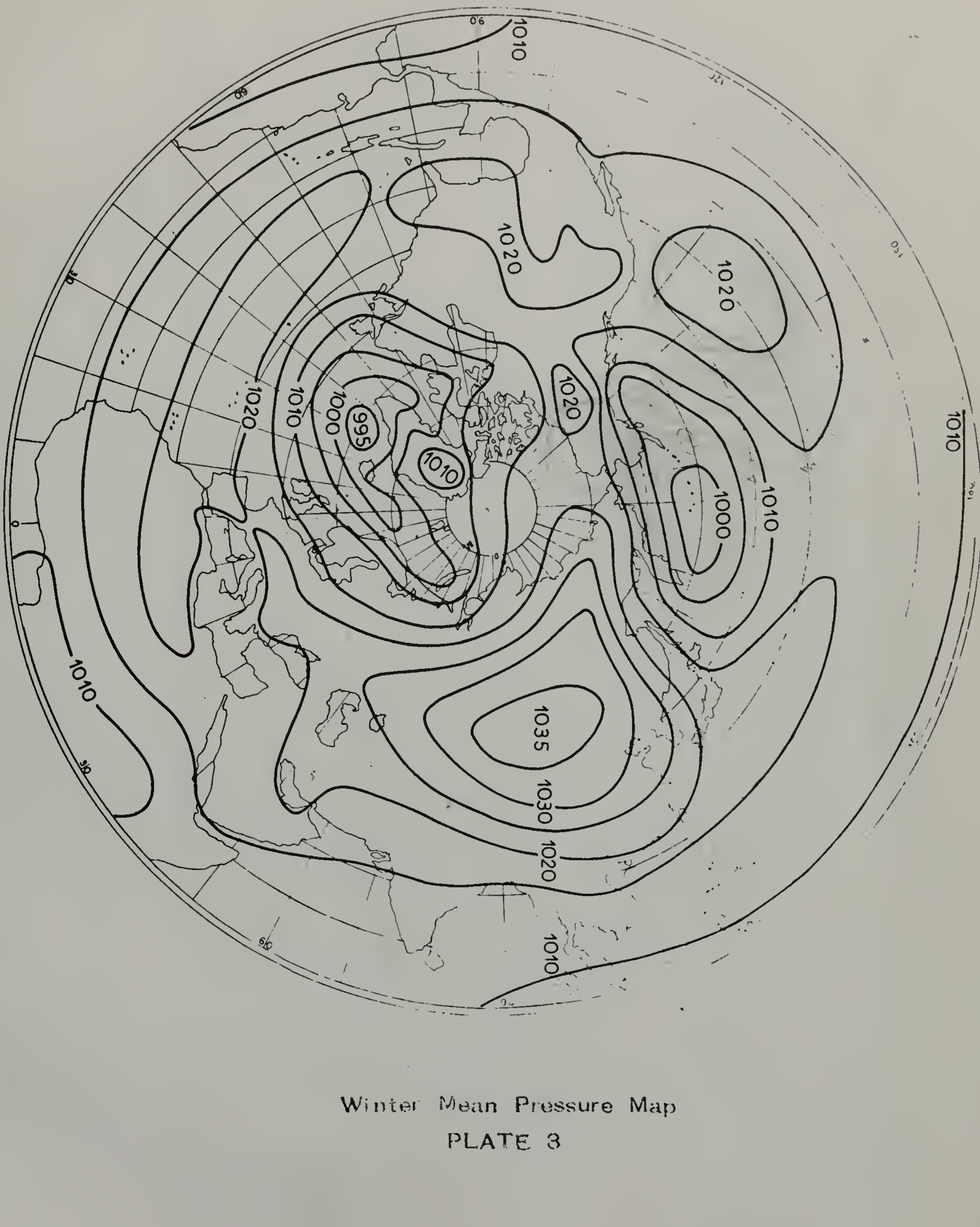
Petterssen's map of the mean pressure distribution of the Northern hemisphere for January, Plate 3, shows an intense and extensive high pressure cell ([illegible] mb.) centered over Central Asia, an extensive high (1020 mb.) centered in the Pacific in latitude 30°N., longitude 140°W., an irregular high ([illegible] mb.) over Central North America, and a smaller high (1020 mb.) over the extreme northeast part of Canada. The Aleutian Low (less than 1000 mb.) is elongated in a NE-SW direction and centers in the western Aleutians at latitude [illegible]°N., longitude [illegible]°E. Petterssen has found that there are two Pacific highs about 54% of the time in winter, one centered in the eastern part at 50°N., 140°W., and the other 30°N., 160°E. About 43% of the time in winter there is only one high, and the remaining 3% of the time three highs.

This mean pressure map gives us the principal or prevailing air currents for the North Pacific in winter. Referring to Petterssen's map of the principal air currents in January in the Northern Hemisphere, Plate 4, we see cold air streaming out of Asia, the Arctic and Alaska southward and southwestward and drawn into cyclonic rotation around the Aleutian Low. Warm moist air from the Pacific High flows northwards and northeastward toward Alaska and North America. The mean velocity field is one of deformation with the axis of dilatation almost parallel to the mean or average isotherms. This situation creates a quasi-permanent zone of frontogenesis, see Plate 4A. This region being one of intense packing of the solenoids becomes therefore the "Weather Factory" of the Pacific. It is here that the PACIFIC POLAR FRONT is formed and maintained.

All the polar air north of the PACIFIC POLAR FRONT comes through the gateway between the Asiatic Monsoon High and the Aleutian Low. This air at the outset is pure Arctic or Polar Siberian Air, but due to its passage over the open sea, it gradually warms up, absorbs moisture and changes its characteristics into Polar Pacific Air. Therefore, there is a constant transition between Polar Continental Air or Arctic Air and Polar Pacific Air west of the Aleutian Low. It is readily recognized that this process is a great natural disturbance of the atmosphere, and in order to compensate for the great masses of air withdrawn from the polar regions some natural force must be set in motion to replace this air. The only way that the warm, less dense air from the south can be transported northwards to replace this outflow is to force the warm air aloft and to the northwards by an occlusion process. The Asiatic High to the west is a barrier to any such process and therefore the Aleutian area figures in this exchange. Waves develop on the PACIFIC POLAR FRONT, move eastward, intensify, bringing all the disagreeable elements of foul weather, occlude into deep cyclones with gale winds and gradually fill up as they pass into the continent.

The part of the Pc air that has been taken up by the circulation of the Aleutian Low will be transformed into Pp air and will arrive off the northwest coast of North America as a current of warmed polar maritime air. This air strikes the Rocky Mountains in Canada and Alaska, rises over them and then remains in the high altitude because the cold, dense Pc air northeast of the mountain range cannot be dislodged from the lowest layers by this less dense air. Hence, between the Arctic or Pc air on one side and the Pp on the other a front is formed which is supported on the Rocky Moontains. This front, known as the PACIFIC ARCTIC FRONT, terminates at its western end in the Aleutian Low.

Referring again to Plate 4, we can see that there is also a zone of converging air currents along the west coast of North America where Tp air streams toward the continent to meet the outflowing Pc air from the American Monsoon High. Here again in this cell a frontogenetical field is established, although it is not nearly so persistent nor intense as the PACIFIC POLAR FRONT. The front developed here between these two highs has its position--from the stmospheric state of mean value--along the Rocky Mountains. This portion of the front through the United States, which forms the southwestern boundary of the Pc air lying over the greater part of the North American continent is designated by the name of the AMERICAN POLAR FRONT. It is in this region that we see the occlusions of the decaying cyclones which have formed on the PACIFIC POLAR FRONT and moved in from the Pacific pushed up against the western mountain barriers so that orographic features augment the converging air currents to establish a quasi-permanent frontogenetical zone lying along the western coast of North America. Since the air from the Pacific High is the warmer of the two masses, it will be aloft, and in the free air the frontal surface of the AMERICAN POLAR FRONT

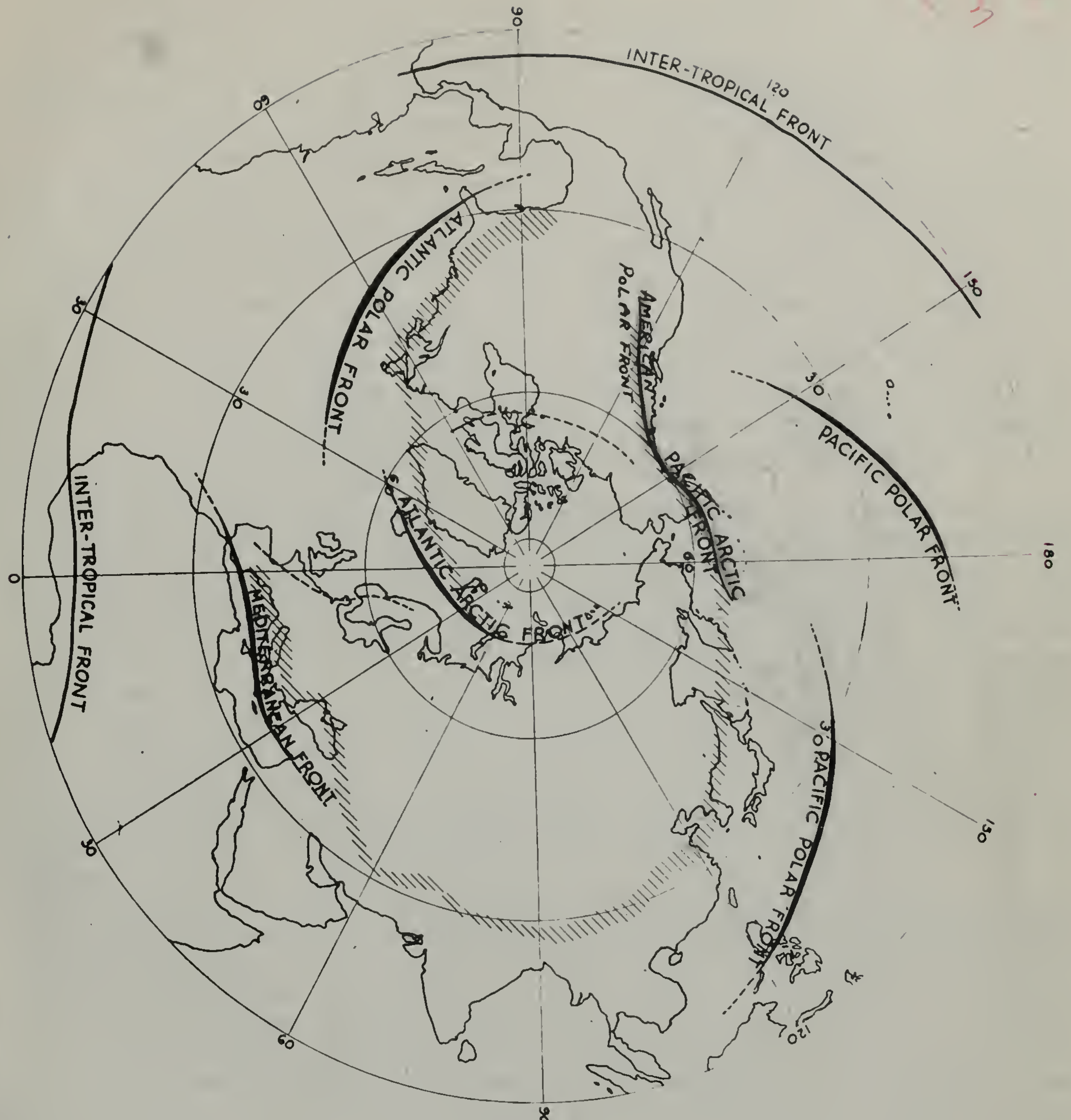


Winter Mean Pressure Map

PLATE 3

Winter Mean Wind Field

PLATE 4



Winter Frontogenetical Zones

PLATE 4A

can be followed farther east. With increasing altitude the subtropical high grows constantly more distinct over the continent and even at the weak point over the Gulf of Mexico. Hence, a low pressure trough must exist between this high pressure belt and the rather shallow North American High. In this trough lies the northward rising, apparently quite flat, frontal surface of the AMERICAN POLAR FRONT. Under certain circumstances the latter may be connected with the ATLANTIC POLAR FRONT which joins it to the eastward. Usually, however, there is a gap between the two.

The foregoing discussion of the PACIFIC ARCTIC and AMERICAN POLAR FRONTS is not meant to imply that these fronts are permanent and definite fronts in any single synoptic situation but rather they mark the zones where fronts moving in from the Pacific (usually occlusions) stagnate and linger for several days at a time. They are the mean positions of quasi-stationary fronts. From its place of origin in the region of Japan, the average storm of the North Pacific moves northeastward toward the Aleutian Islands and occlusion begins. By the time the frontal systems have passed into the Gulf of Alaska, they are usually occluded. From there they pass into Canada and the northern part of the United States as occluded fronts and stagnate along the mountain ranges. The AMERICAN POLAR FRONT may be considered as the southern extension of the PACIFIC FRONT since it is practically impossible to tell where one begins and the other ends most of the time.

Often occlusion takes place over the ocean because of the slowing down, halting, or complete reversal of direction of the warm front. This is brought about by action of high pressure areas which the warm front encounters. The warm sectors formed in the southern part of the North Pacific are particularly subject to this effect on account of the movement of the trade winds from the northeast. Compare this action with that found in the semipermanent low pressure region of the Aleutian Islands where occlusion takes place by the cold air overtaking the warm and displacing it upward. Because of the steady cyclonic circulation the Aleutian Low becomes the focal center of the cyclone family and the fronts, mostly occluded, move around it like the spokes of a wheel, in much the same way as in the Icelandic Low of the Atlantic. The frontal movement is restricted, however, to the southern half of the cyclone only, for the mountains prevent the passage of fronts northward through Alaska.

In the region about Alaska, cyclones which appear to be dying out as they cross the Pacific Ocean are sometimes strongly regenerated, although for most of them the Gulf of Alaska acts as a region of degeneration. In these cases this can be traced to the frontogenetical action of the Aleutian Low. A wave with a long narrow warm sector moves into the Gulf of Alaska and occludes along the coast. Orographic features cause the low to acquire an elliptical shape with the major axis running approximately WSW-ENE, while at the same time the intense cyclonic circulation causes the occlusion to rotate counter-clockwise until the major axis is finally SSW-NNE. The axis of dilatation will now be 45^0 clockwise from this or WSW-ENE, which is parallel to the mean isotherms of this region and very active frontogenesis results. Secondary waves develop along this front and deepen, thus intensifying the cyclonic circulation already in existence.

Another important region of frontogenesis is in the vicinity of the Hawaiian Islands. It is in this region that the Kona storms develop (Daingerfield, 1921). These storms form as waves in quasi-stationary cold fronts and usually are slow in developing or die out completely. Their greatest energy is attained when they form as new or secondary fronts in connection with another frontal system centered farther northward. When they develop strongly they are often very vigorous. Their proximity to the Pacific anticyclone hampers their growth, for they are likely to encounter strong northeast winds which may displace the air of the warm sector.

PRINCIPAL AIR CURRENTS IN SUMMER

Referring to Plate 5, we see an extensive high throughout the North Pacific centered at 37°N. and 150°W. Petterssen has found that this high is a single cell in the summer 74% of the time and has two separate centers the remainder of the time. The general distribution over North America shows a weak low in the north and another in the arid regions of the Southwest. Asia shows an extensive low in the south. This distribution maintains a constant summer monsoon over Asia and a weaker monsoonal circulation over North America.

Plate 6 shows the resultant general circulation. It is readily apparent that no well-developed zone of frontogenesis exists in the Aleutians such as there is in the winter; however, the Arctic regions are a zone of weak high pressure and divergent winds, so that the POLAR FRONT does exist at about 70°N. where the warm air from the Pacific comes into contact with the cold Arctic air.

Warm Tp air flowing over the colder waters of the North Pacific (see Zone 3, Plate 2) is cooled down to or below the dew point at the surface so that summer is a season of frequent and persistent fogs in the North Pacific. It is rarely that visibility is good, and that occurs only when there is an occasional outbreak of Pc or Arctic air to push the POLAR FRONT farther south than usual.

The winds are generally light throughout the whole region in summer, which condition is further conducive to fog formation. The Weather Bureau's Atlas of the Climatic Conditions of the Oceans shows for the summer months fog over 10% of the time north of a line roughly along 40°N. and over 20% of the time north of 45°N. and west of 170°W., while in the Bering Sea it averages over 25% of the time. Stratus or Strato-cumulus clouds persist over the entire Pacific Ocean north of latitude 30°N. over 30% of the time, while north of 45°N. and west of 150°W. they are found over 40% of the time. A narrow strip about 200 miles wide extending along the coast of North America from Kodiak Island to Lower California averages between 20 and 30% of the time stratus or strato-cumulus clouds.

Since fog or low strato-form clouds and weak circulation are the main characteristics of this region in summer and no marked cyclonic activity prevails, no further consideration of the summer conditions will be undertaken and the remainder of the work will be confined to the winter months. It is only in winter that cyclonic activity becomes so marked that flying conditions change rapidly from the worst to the best and vice versa.

PART III

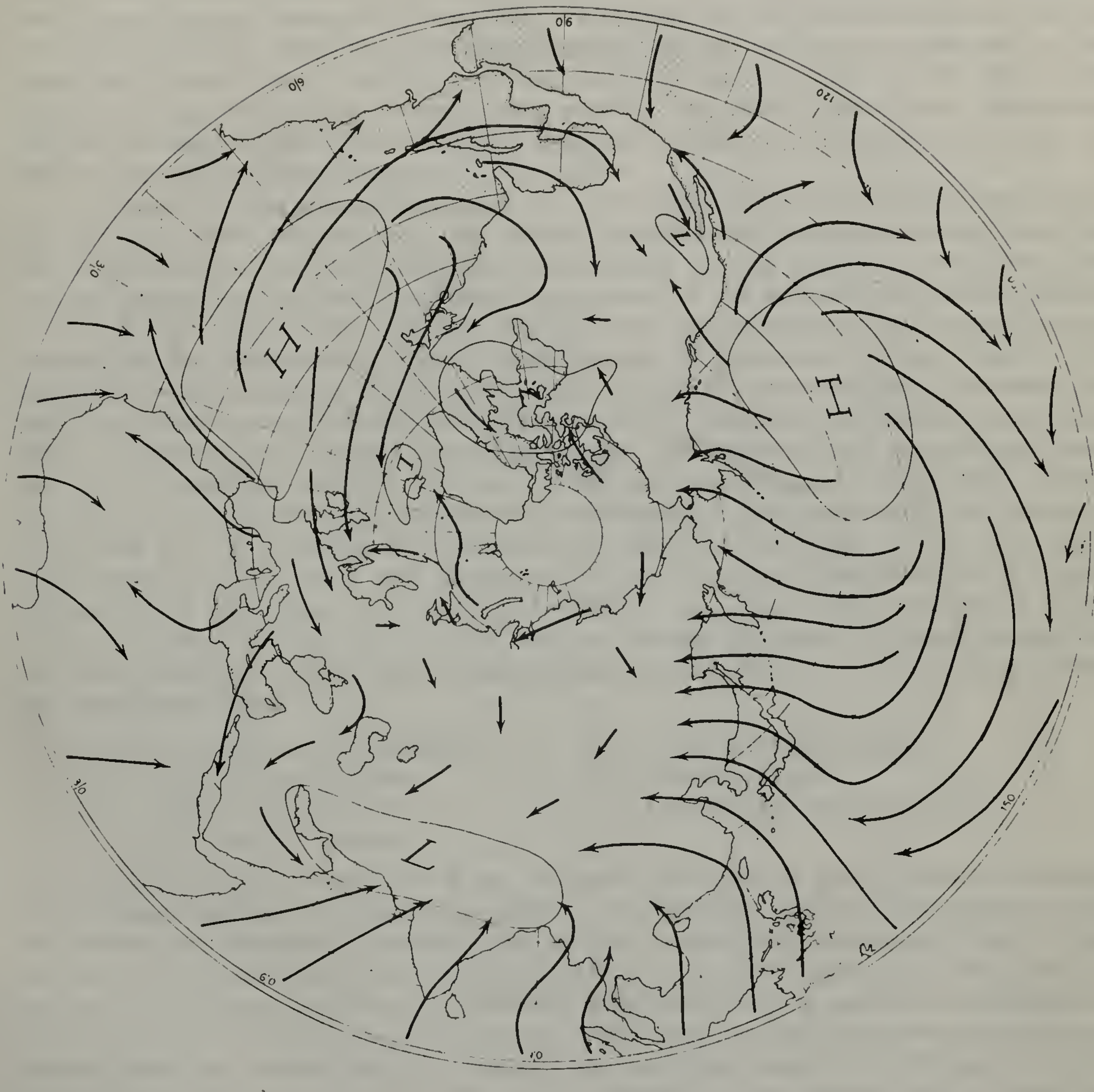
EVOLUTION OF THE TYPE CLASSIFICATION

It was discovered early in the examination of the several hundred weather maps mentioned in Part I that centers of action moving into the North American continent from the Pacific undergo great modification or disappear entirely upon striking the western mountain barrier. The colder Pc air east of the mountains cannot be dislodged by the overriding warmer Pp, Npp, or Tp air from the ocean. The hope that some correlation existed between the weather conditions on the continent and over the ocean was nipped in the bud. Too much of the continental weather is influenced by interaction between Pc air from the continental high and Tg air from the Gulf of Mexico or the Western Atlantic. It is true that pressure tendencies and frontal precipitation along the Pacific coast give indications of approaching systems, and it is upon these that we shall depend mainly to establish the weather type existing off shore.

Willett has found a fair correlation between the deepening of the Aleutian

Summer Mean Pressure Map

PLATE 5



Summer Mean Wind Field

PLATE 6

Low and the filling of the Great Basin High for five day means; but this correlation becomes doubtful and uncertain for daily situations. Krick, working independently, has reached similar conclusions and accepted the same principle--that is some correlation between the Aleutian Low and the Great Basin High. Rossby, also working on five day means, has found a definite correlation between the Zonal Circulation for the entire globe (latitude 30-55°N.) and the intensity and position of the major centers of action, such as the Aleutian Low and Icelandic Low; but here again this correlation begins to fail as soon as we confine our Zonal Circulation to a sector as small as the United States or reduce our time element to a single synoptic situation. As stated earlier, this instantaneous correlation may become more apparent in the upper air, since most of the air currents from the Pacific remain aloft after being driven up over the Rocky Mountains. But until we can obtain data from a denser network of aerological and pilot balloon stations, any such correlation must remain the subject for future investigation.

From the above considerations, it is evident that the synoptic surface weather pattern over North America will not have a simultaneous correlation with that over the North Pacific. If any correlation does exist, it will be a lag correlation—the surface weather over the Pacific being a forerunner of the continental surface weather.

We are faced then with the gigantic task of determining the weather conditions over the wide expanse of the North Pacific Ocean without direct observations in that ocean and only a fringe of coastal and island observations. To meet this task only one practical solution presents itself: Classify the weather situations over the Pacific into general types and use all available coastal and island observations to establish the type existing in any one single synoptic situation. In the event of war in the Pacific, the weather observations from ships will be reduced to a minumum and at times none at all will be obtained; however, it is felt that a meteorologist in the ocean can determine the type by careful analysis and a logical sequence from preceding maps. He will have at least one good observation in the ocean: his own. In addition to the belt of coastal stations of North America the following stations will be able to furnish the Naval forecaster with reliable surface and aerological data;

(1) St. Paul's Island
(2) Kanaga Island
(3) Dutch Harbor
(4) Kodiak Island
(5) Pearl Harbor, Hawaii
(6) Midway Island
(7) Aerological Units Afloat

Fortunately, there are a few of these stations in the regions of greatest frontogenesis and cyclonic activity--namely, the Aleutian area and the Hawaiian area. The largest and predominating center of action is the great subtropical Pacific High and therefore it is upon this cell--its extent and orientation--that the classification of the types is based. A thorough groundwork in the general circulation, a careful analysis of the available reports, and a logical sequence from preceding maps should enable the synoptician to establish the position, extent and orientation of the Pacific High and once this is known, a fair picture of the weather over a large part of the ocean has been determined. The solution in the absence of direct observations will, of necessity, be more or less inaccurate, but even an inaccurate map (if treated as such) is far better than a pure white blank.

The true picture of any individual synoptic situation is necessarily blurred by a mean map of the air currents or the pressure field. A discussion of general frontal movements is therefore appropriate to an understanding of the variations from the mean pressure distribution and prevailing air currents. The sequence of events is usually as follows: Starting with the PACIFIC POLAR FRONT in the frontogenetical zone as in Plate 4A, a series of waves develops, each one passing into the warm sector cyclone stage and then occlusion. The cyclones travel eastward at an average speed of about 700 miles a day until occluded, then they slow down and fill up. Each cyclone is followed by an anticyclone of cold air to the west, causing the POLAR FRONT to be driven farther and farther south and southeastward with each succeeding cyclone. Eventually, the cold air finds itself being heated by increased solar radiation, increased sea temperatures and subsidence. The POLAR FRONT has passed out of the zone of frontogenesis; it becomes weaker and finally dissolves. The air that was once Pc, Pp, or Arctic stagnates in the lower latitudes where it has displaced Tp, which went aloft and to the northward in the warm sectors. The Pp air undergoes transition into Transitional Polar Pacific (Npp) and finally into Tp and becomes a part of the Pacific High.

Meanwhile this transitional air flowing back northward around the Pacific High is much warmer than air from the Siberian High and a new front is created in the western Pacific in the Pacific Polar Frontogenetical Zone. A new series of waves is set up and the above sequence is repeated.

Surface observations, in particular temperature discontinuities, barometric tendencies, and pre-frontal precipitation, along the west coast of North America will serve to locate the latitudinal position of the PACIFIC POLAR FRONT and the approaching cyclones. Having determined the position of one cyclone, we can locate the following one approximately by extrapolating the front westward from the coast a distance of one wave length, the average of which is about 1500 miles when the cyclones are not yet occluded. Experience shows that the farther south the POLAR FRONT is, the farther east the cyclones are before they occlude until in the latitude of California occlusion usually occurs along the mountain ranges after passing inland.

When the front lies along the Aleutians, the cyclones have reached such a stage of development by the time they have crossed the 180th meridian, they are already deeply occluded. Therefore, appearance of a deep, occluded cyclone in the region west of California is a signal that the southerly system is decaying and a new series is starting. If we can determine from continental observations some indication of the trajectory of this new cyclone and its strength and tendency, we have made some progress toward a forecast of the general weather over the ocean.

To be more specific, a very deep, strong low with stationary or rising tendency would mean an occluded system. In this case, knowing the average radius of such systems to be approximately 800 miles, we could place the occlusion and cold front according to the normal model for such a system. On the other hand, a low of only moderate intensity (i.e. pressure higher than 992 mb.) and having a falling tendency would mean an open warm sector and a rapid deepening could be expected. The fronts would be drawn according to the warm sector model of a typical cyclone. Fortunately, cyclones over the oceans, due to the homogeneity of the surface and its temperatures, are generally very close to the ideal model and rarely assume distorted shapes. Otherwise, fronts could not be so arbitrarily placed with any assurance of their correctness. As it is, the absence of direct observations makes the exact location of fronts subject to errors which may amount to several hundred miles even when the location of the center of the low pressure system, its intensity and tendency are accurately known. It must be remembered that a logical sequence from one day to the next under these circumstances is the best guide the analyst has at his disposal for the placement of fronts. The best we can hope for is an approximate picture of the general situation deduced from approximately placed highs and lows.

Believing, therefore, that the dominant feature of any synoptic weather map of the North Pacific Ocean is the huge, semipermanent anticyclone of the middle latitudes, the authors after an intensive study of the maps listed in Part I have reached the conclusion that the winter synoptic situations fall into the following types:

ORIENTATION OF MAJOR AXIS OF PACIFIC HIGH

TYPE	
A	East-west
B	Northeast-southwest
C	North-south in the eastern part of the ocean area
D_1	Northwest-southeast with deep low in Gulf of Alaska
D_2	Northwest-southeast with high bordering the coast
E	North-south in the western part of the ocean area
F	No high—Whole area dominated by cyclonic vorticity

PART IV

DESCRIPTION OF THE TYPES

A detailed description follows in which each type is discussed from four aspects:

1. General Features
2. Weather
3. Indications
4. Trend

Naturally any individual day will never fit exactly any one of the typical examples presented; but there will hardly be a case which will not fall into one of the types selected. Individual cyclones and fronts will vary the details of the picture; but if it is remembered that the Pacific High is the dominant system indications from the observations available, when carefully analyzed, should point definitely toward one of the types.

The weather is only briefly and generally discussed because the statistical data on Plates 7-13 present it much more in detail and graphically.

The trends are those which actually occurred during the winter of the Polar Year 1932-33, although possible variations have been considered. Plate 14 shows the prevalence, persistence, and shifts of the types for that period.

DATA USED IN RESEARCH

Inasmuch as the research has been confined to the Polar Year of 1932-33, it is deemed advisable to explain this decision and the source of data.

In 1932 the International Meteorological Organization commissioned the Deutsche Seewarte of Hamburg, Germany, to construct a set of Northern Hemisphere Synoptic Weather Maps. These maps were to be constructed primarily for research purposes, and consequently they were not used for current weather forecasts. By means of bulletins, notices and the like, the word that these maps were to be constructed was spread around the world and observers were asked to cooperate in every way possible. Special stations were established in the vicinity of the North Pole and continuous data recorded for a meteorological year--whence comes the name "Polar Year". Special instructions were given for filing reports, and this made it possible for the Deutsche Seewarte to receive a complete copy of all the significant meteorological observations taken in the Northern Hemisphere during the Polar Year. When all the reports had been received, they were entered on the maps and an analysis completed by the expert staff of the Deutsche Seewarte. This analysis was then published with only the representative meteorological observations on the chart. In consideration of the above it can be seen that the Deutsche Seewarte Maps that were published under the auspices of the International Meteorological Organization, and in particular those maps for the Polar Year of 1932-33, should rank with the best data available for a statistical research problem.

Other sources of data were examined carefully, but in each instance it was noted that the data were not as complete nor did they appear to be as reliable as those of the Deutsche Seewarte. This can easily be explained when one considers the fact that most synoptic weather maps are constructed for current use, and in many cases the historical sequence seems to center about a few very good reports than can be found on each map. It would require a large staff to correct the previous maps in order to maintain the historical sequence, and it is here that the great advantage of the Deutsche Seewarte is realized. Since these maps were published several years subsequent to the observations, an accurate historical sequence can be maintained and very difficult situations analyzed correctly.

As a conclusion to the above discussion the authors have decided to confine the statistical analysis of this paper to the 3493 complete ship meteorological observations that they were able to take from the Deutsche Seewarte Maps for the Polar Year of 1932-33 and feel confident that each report is a representative one. Other sources would have netted approximately 1000 additional observations and many of these would be doubtful. In a statistical research such as this paper the authors conclude that a few excellent observations are more significant then many mediocre ones.

DESCRIPTION OF PLATES SHOWING WEATHER TYPES

The following plates, numbers 7 to 13 inclusive, are so arranged that the upper diagram gives the typical pressure distribution over the Eastern North Pacific for the specific type named on the plate. The lower diagram is a representation of areas of 10^0 longitude by 5^0 latitude for the area investigated. For each such area all the reports that were noted in the area were averaged and the average entered as given in the key in the lower right-hand corner of the plate. A description of the key follows: The data entered on the left-hand side of each individual area gives the percentage of observations for which the following were noted:

a) Snow
b) Unclassified rain
c) Drizzle
d) Showers
e) Squalls
f) Dense fog
g) Light fog
h) Haze

Where no such observations were noted the percentage is omitted. In the center of the individual areas the figures from top to bottom are as follows:

a) Total number of observations in area for the type.
b) Percentage of clear reports (0 to 0.3 clouds).
c) Average clouds (average of all reports).
d) Percentage of overcast reports (0.9 to 1.0 clouds).

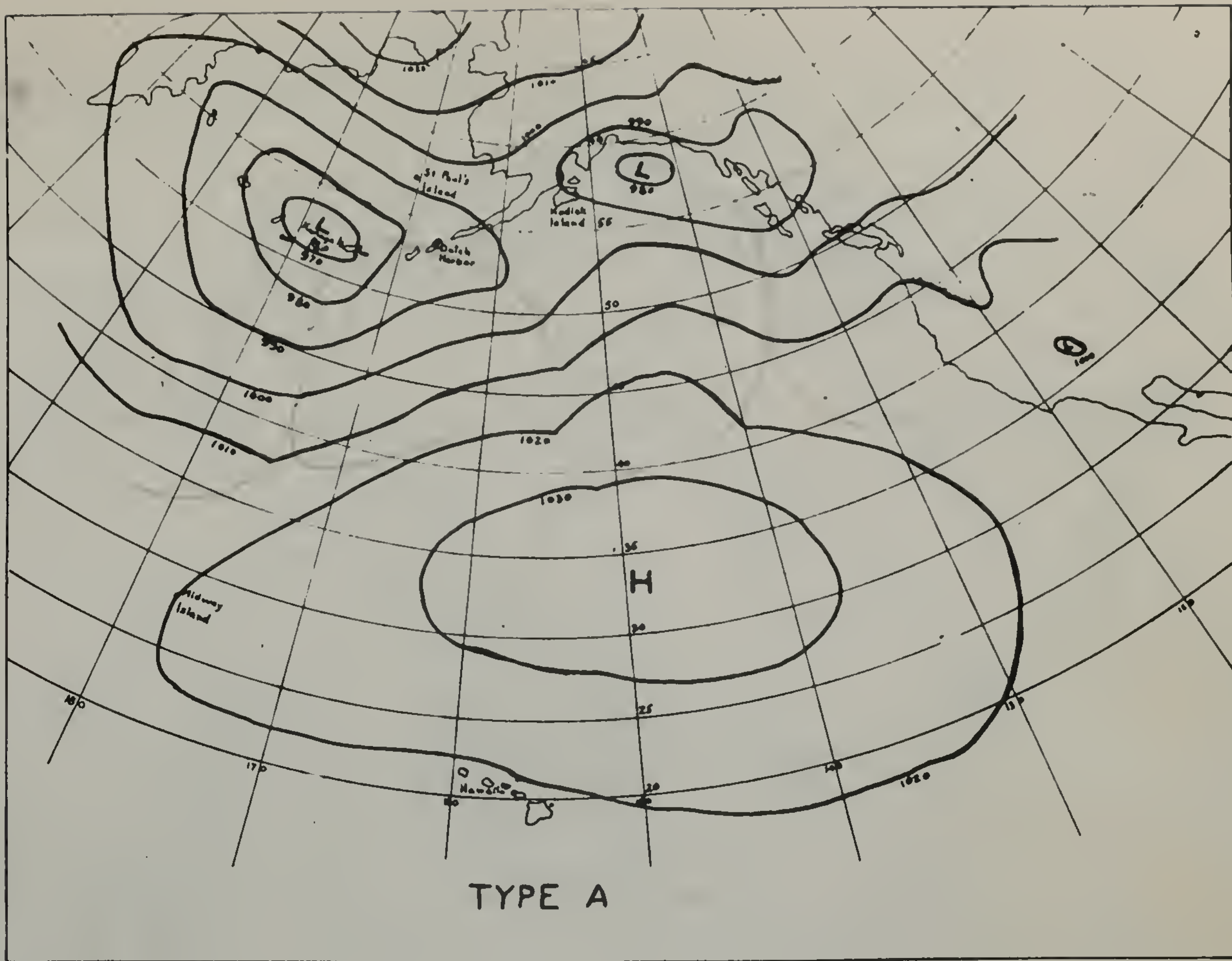
On the right-hand side of the individual areas is entered from top to bottom the percentage of the total observations that reported the following Beaufort wind forces:

a) 0 to 3 inclusive.
b) 4 to 5 inclusive.
c) 6 to 7 inclusive.
d) 8 and greater.

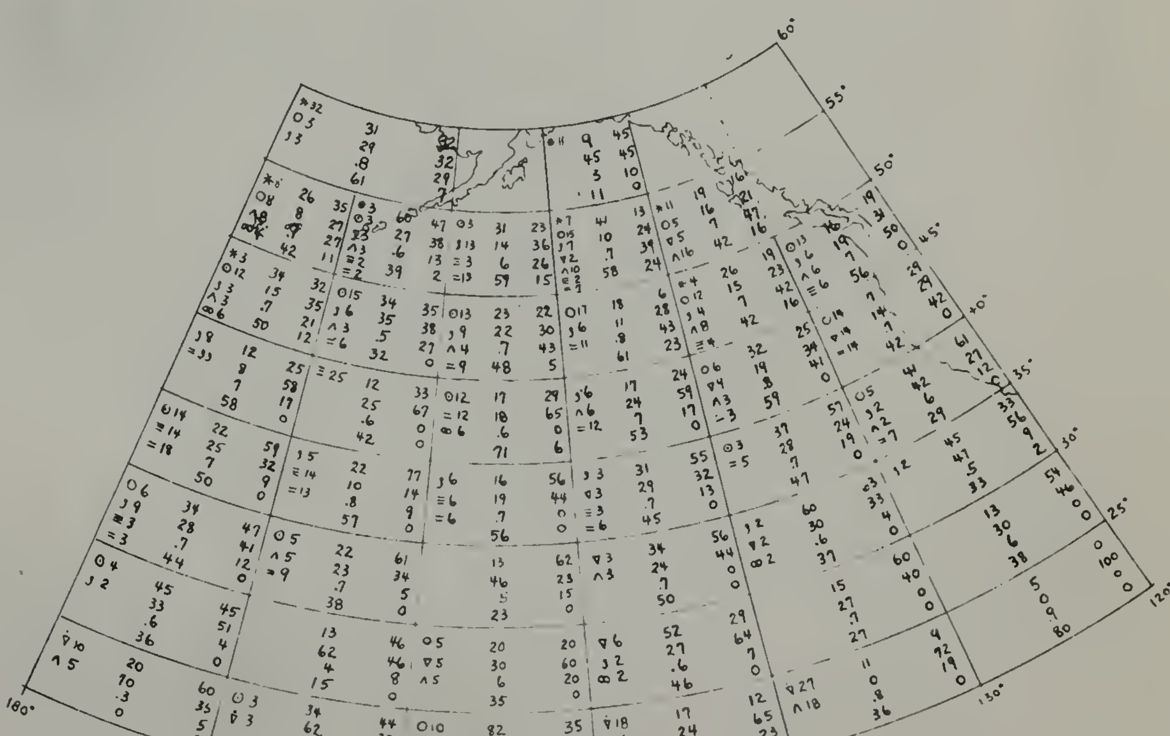
TYPE A (Plate 7)

GENERAL FEATURES

Type A is the most prevalent of all the types selected, and together with Type B, which is hardly more than a variation of this type, constitutes the weather pattern over the North Pacific Ocean more than 60% of the time during the winter months of December, January and February. Types A and B are similar to Reed's South-

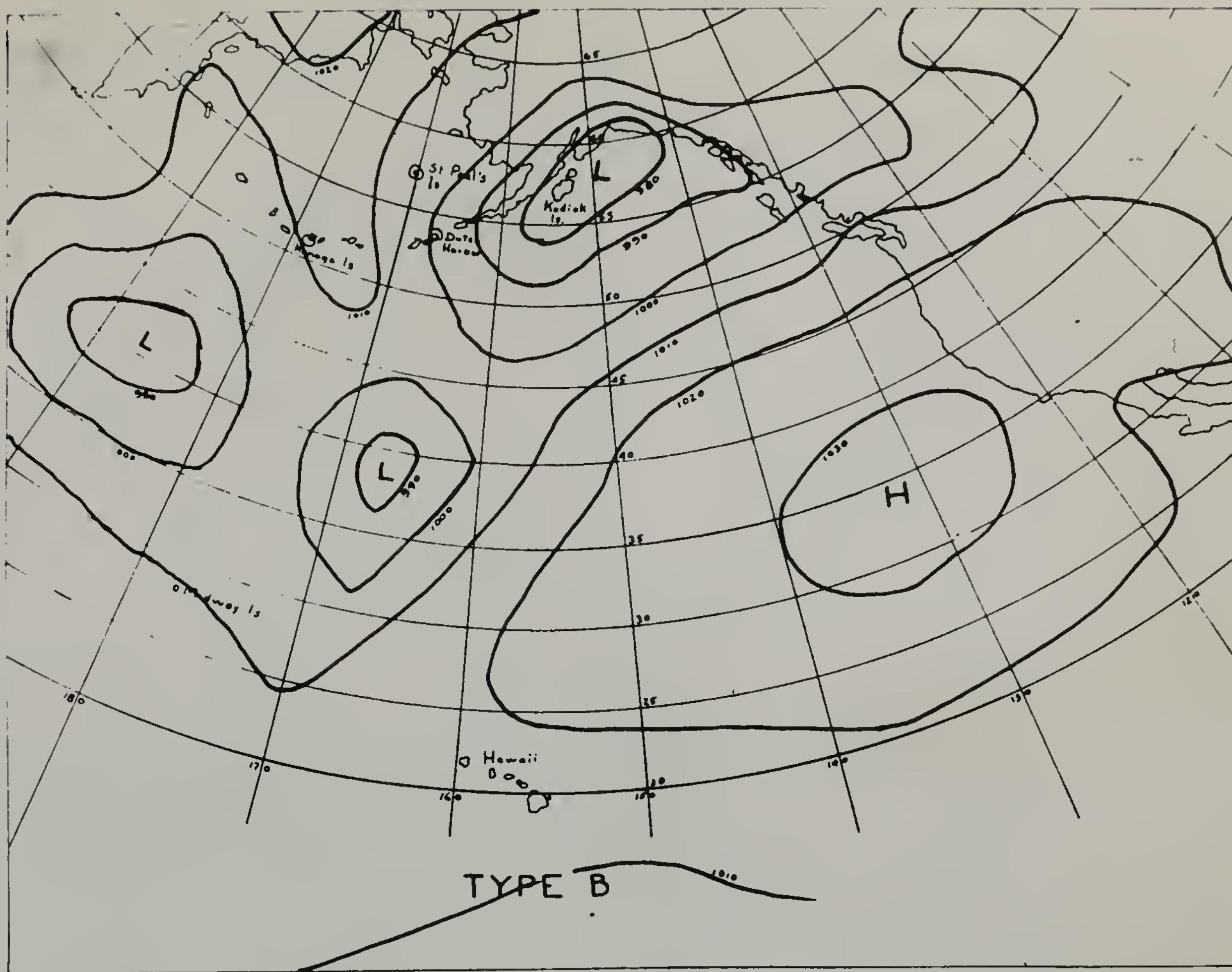


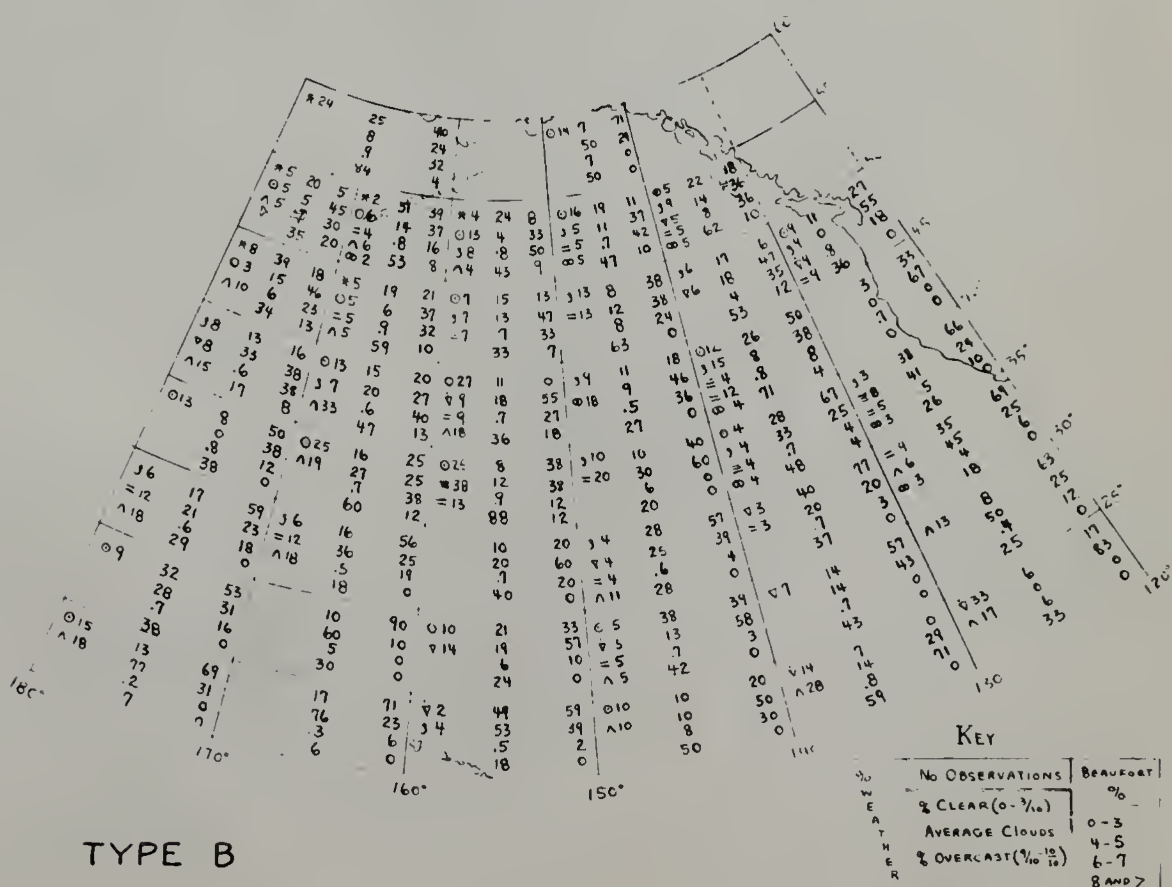
TYPE A



TYPE A

PLATE 7

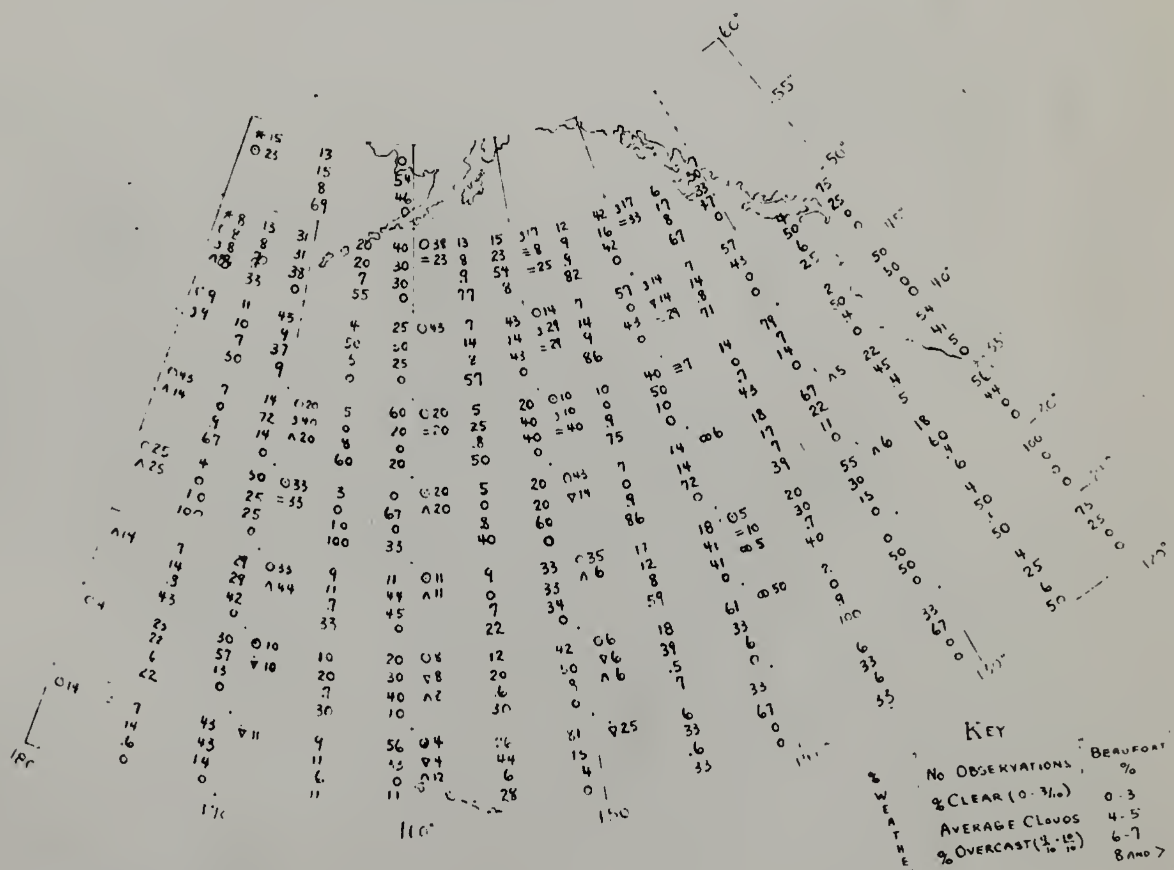




TYPE B

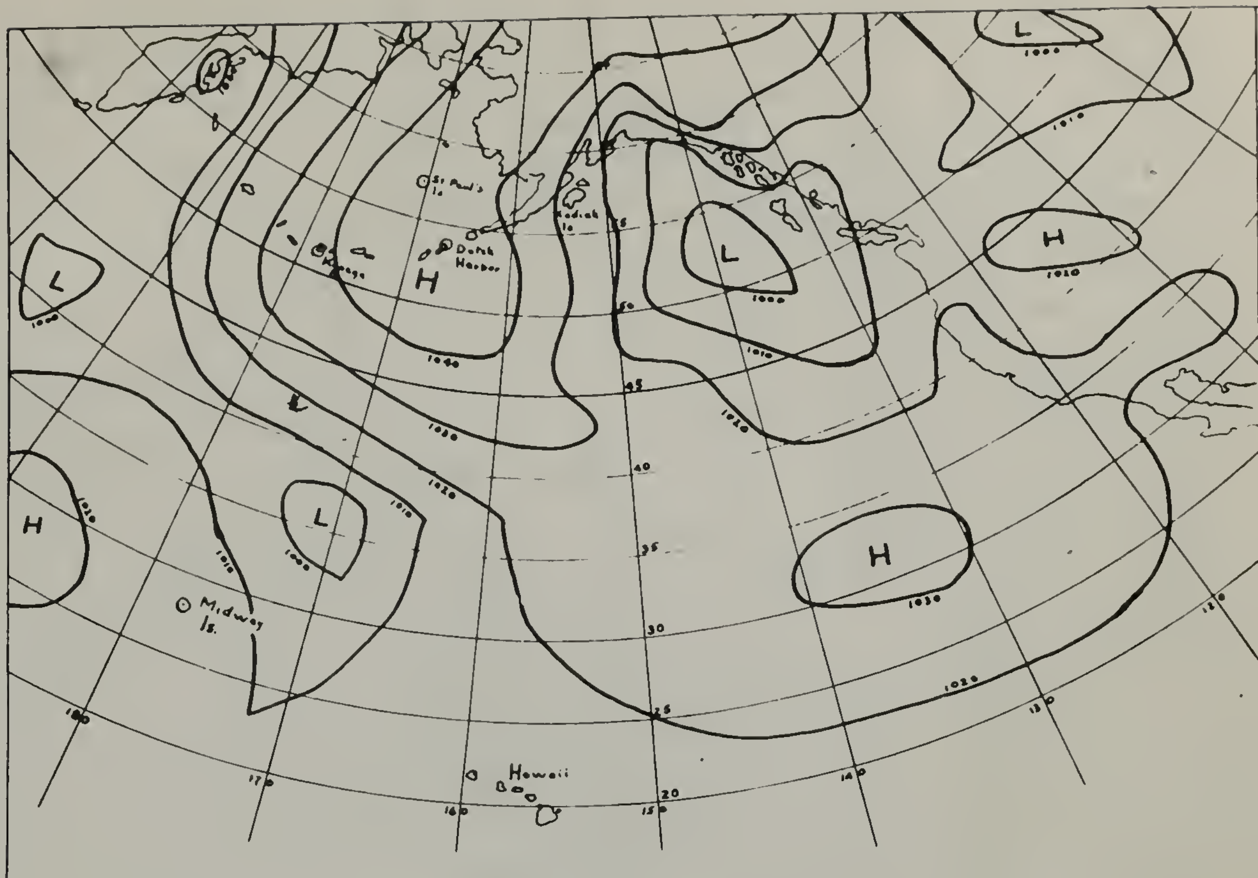
PLATE 8

TYPE C

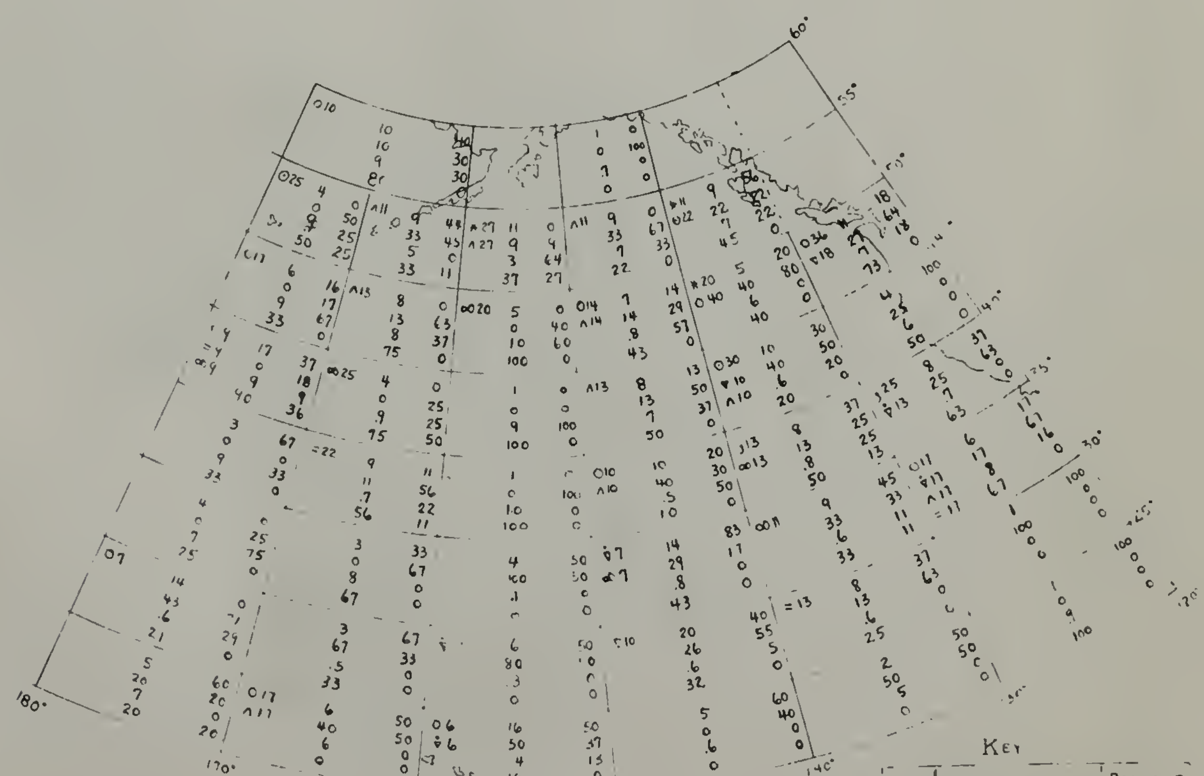


TYPE C

PLATE 9



TYPE D1

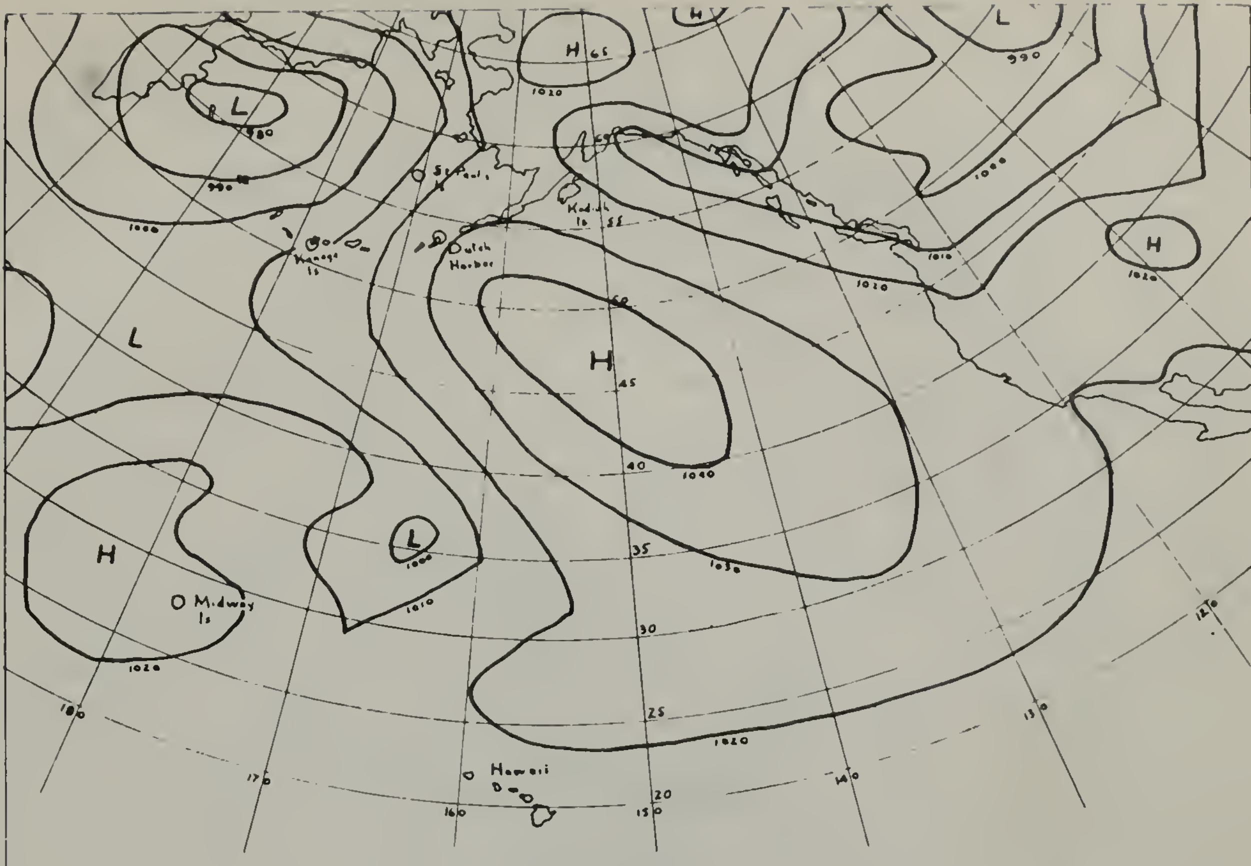


TYPE D1

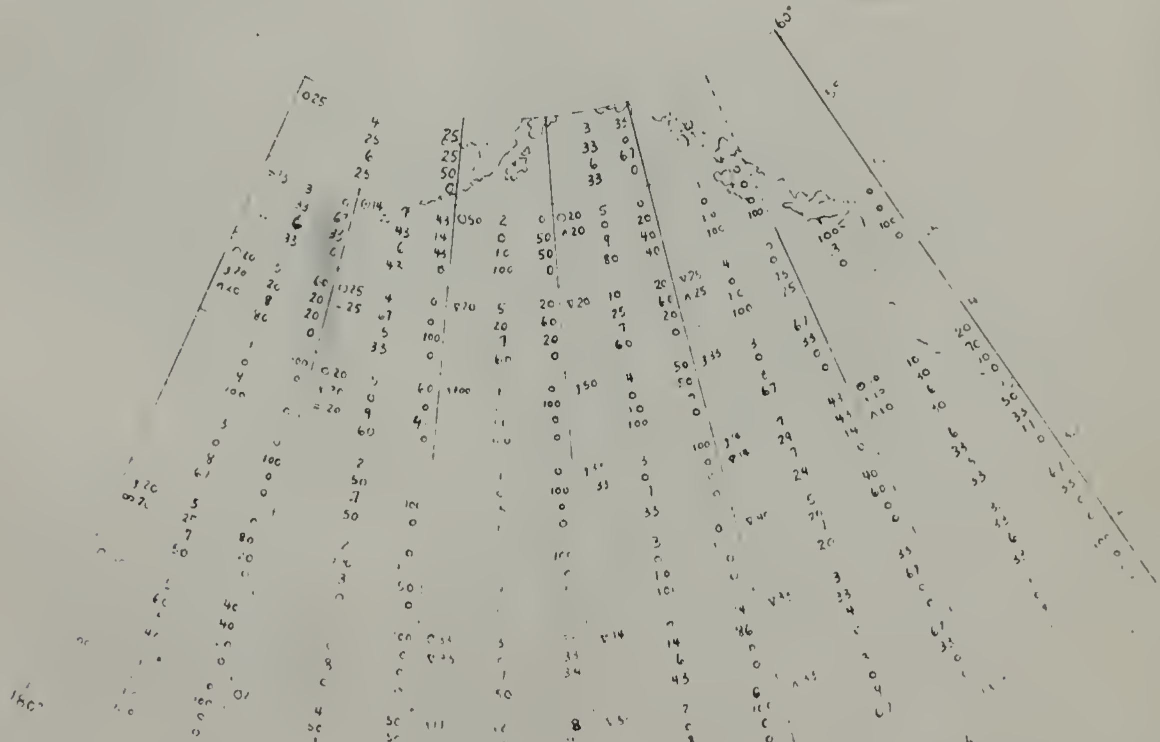
KEY

WEATHER		BEAUFORT %
	No Observations	
	⊙ Clear (0 - 3/10)	0-3
	Average Clouds	4-5
	⊕ Overcast (8/10 - 10/10)	6-7
		8 and 7

PLATE 10

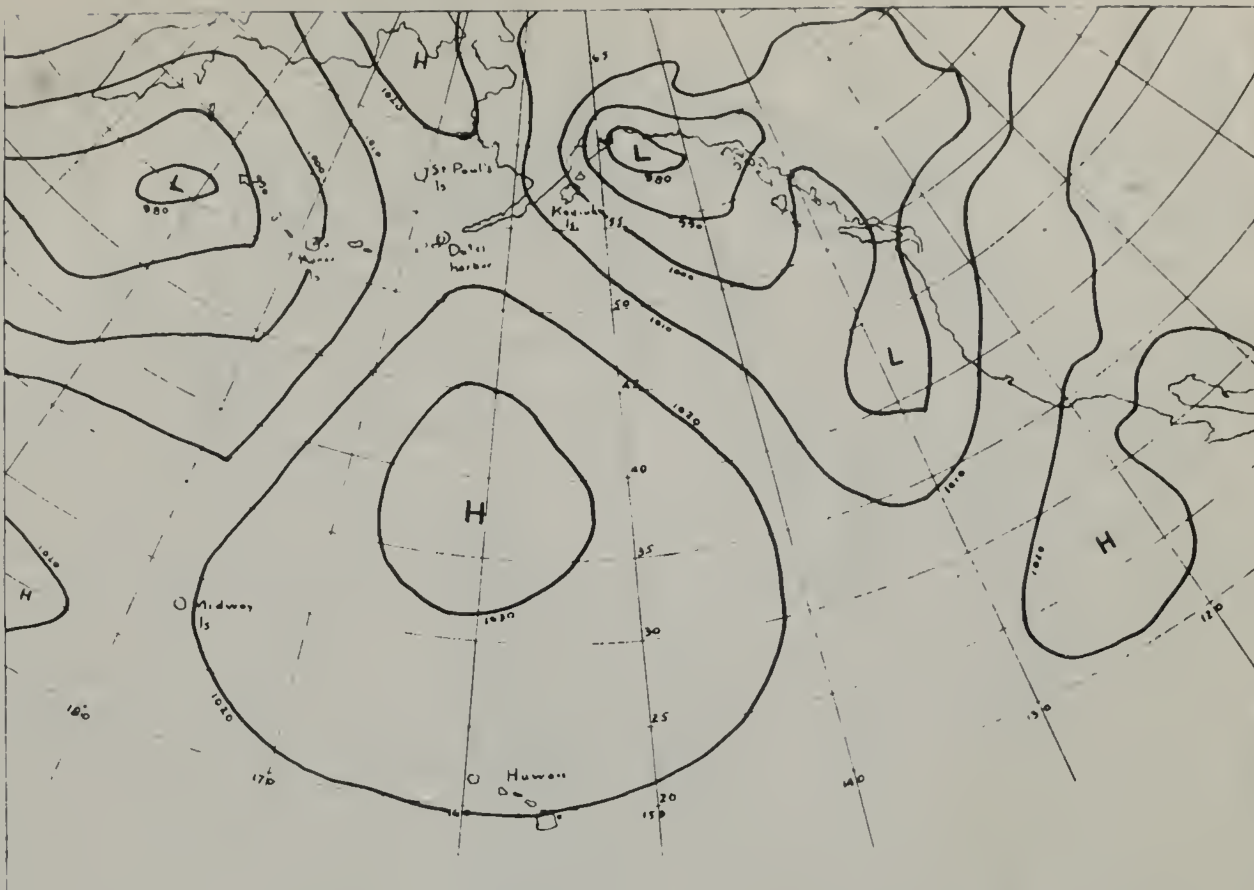


TYPE D_2

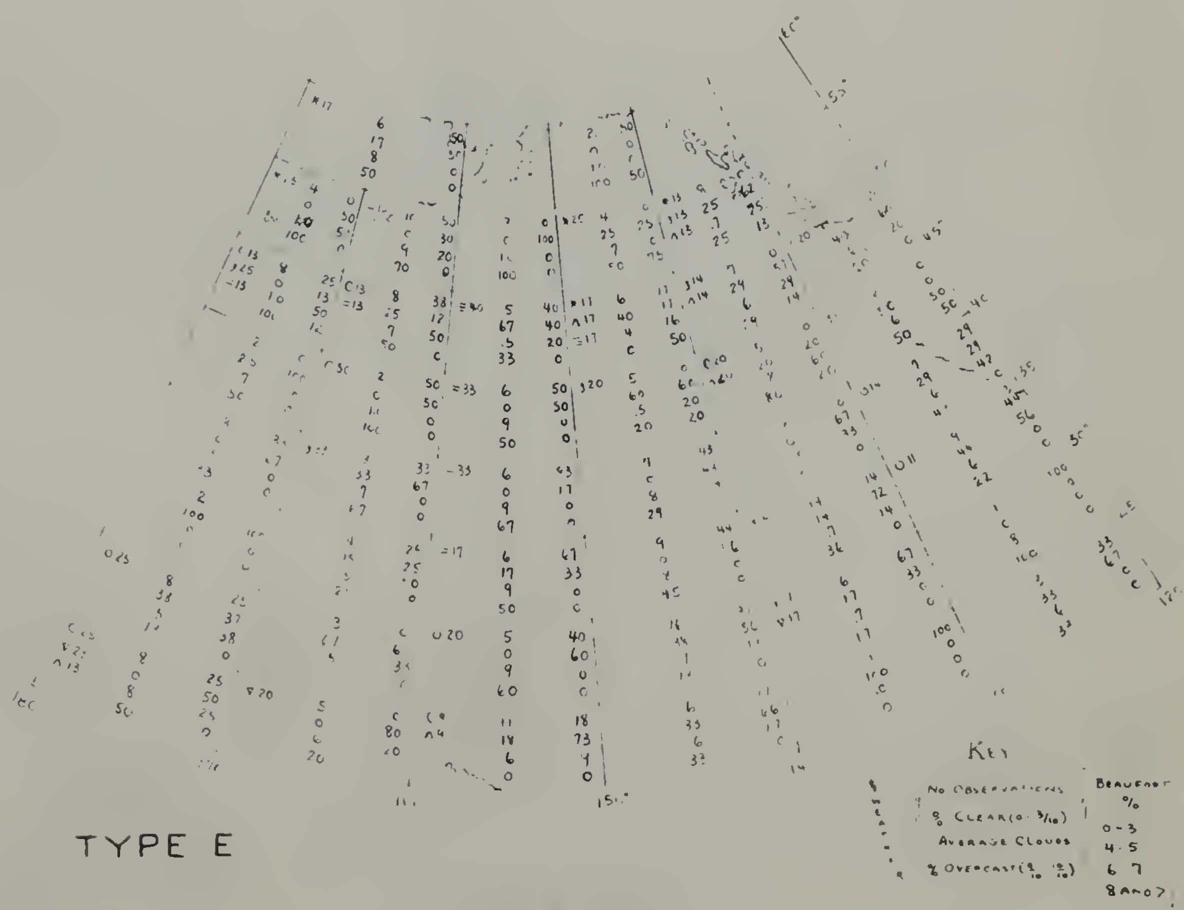


TYPE D_2

PLATE II

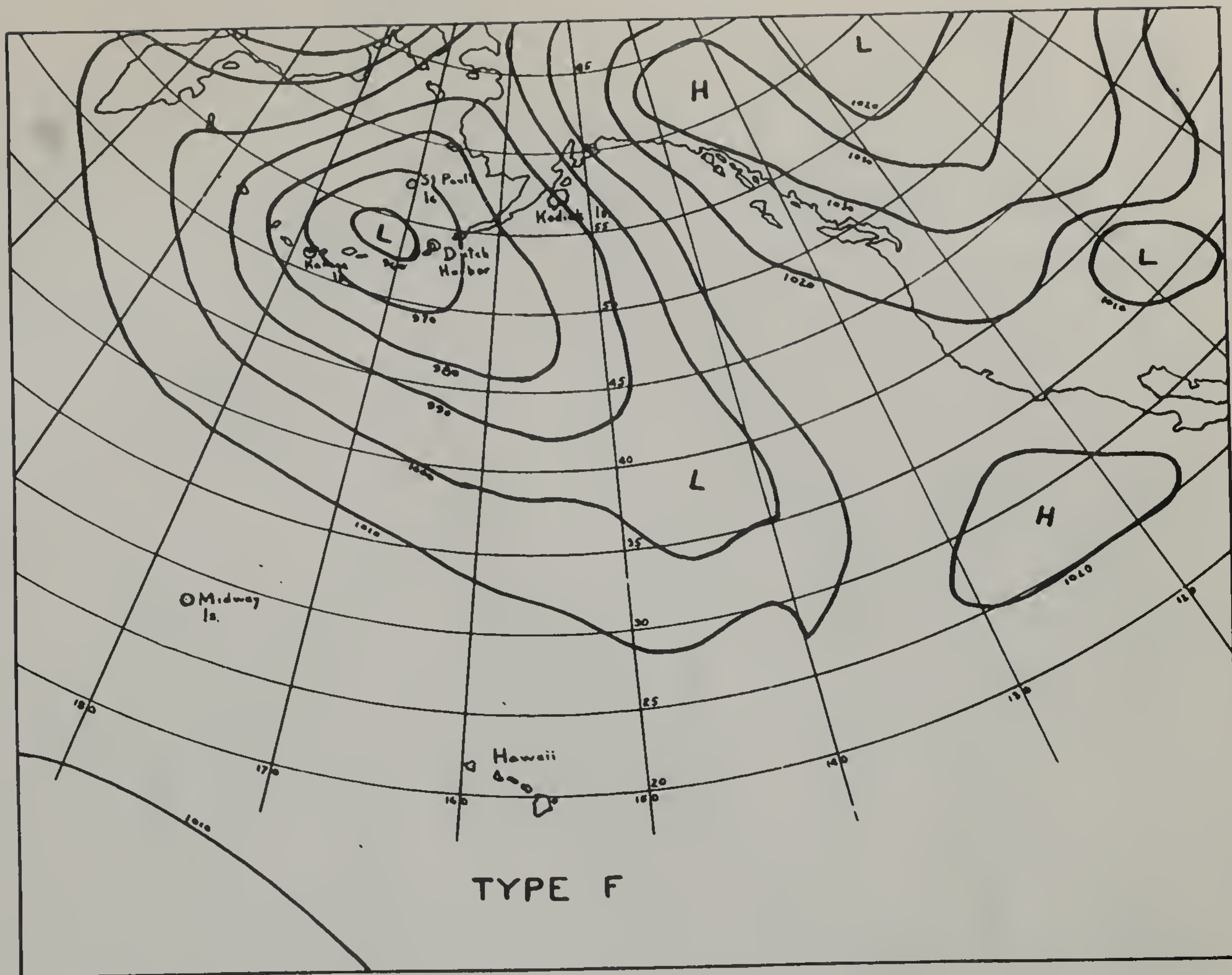


TYPE E

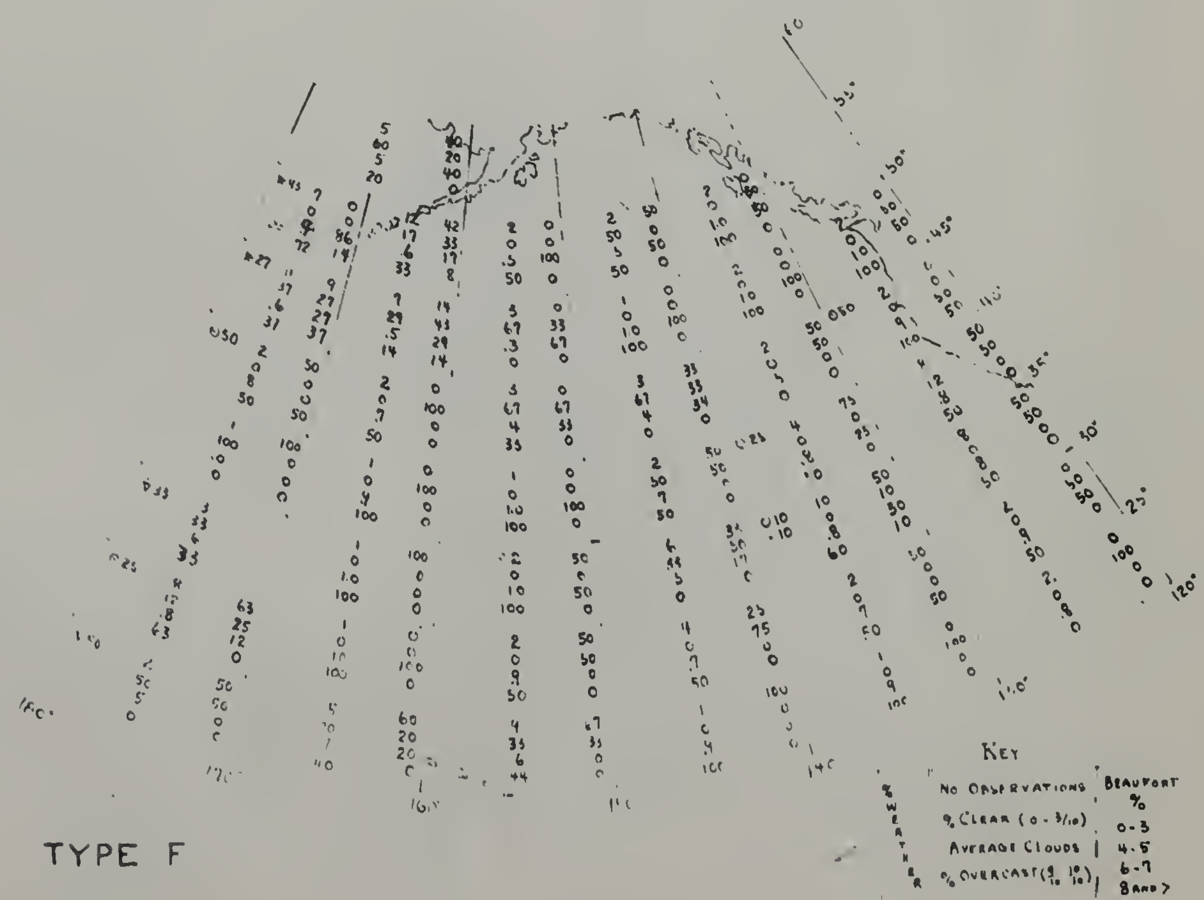


TYPE E

PLATE 12



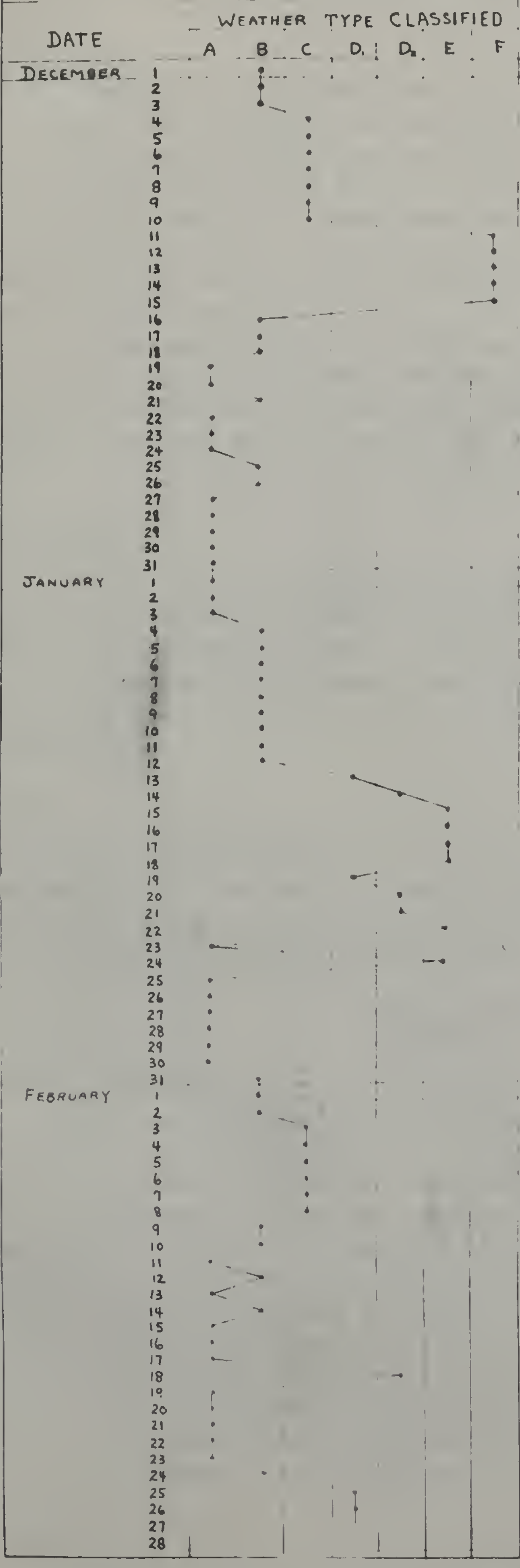
TYPE F



TYPE F

PLATE 13

TYPE CLASSIFICATION FOR POLAR YEAR 1932-33



MONTHLY SUMMARY

	December	January	February
A	10	10	10
B	9	10	7
C	7	0	6
D_1	0	2	4
D_2	0	3	1
E	0	6	0
F	5	0	0
TOTAL	31	31	28

WINTER SUMMARY

SUMMARY OF TYPES

	A	B	C	D_1	D_2	E	F
DEC.	10	9	7	0	0	0	5
JAN.	10	10	0	2	3	6	0
FEB.	10	7	6	4	1	0	0
TOTAL	30	26	13	6	4	6	5
SUM TOTAL							90
%	33	29	14	7	4	7	6

CONSECUTIVE DAYS FOR TYPE

	MAX	MIN
A	8	1
B	9	1
C	7	6
D_1	4	1
D_2	2	1
E	4	1
F	5	–

MEAN SHIFT OF TYPES

FROM	TO
A	B
B	C
C	B OR F
D_1	D_2
D_2	E
E	A
F	B

PLATE 14

westerly type, named after the prevailing air currents striking the Pacific northwest coast. The main features of the type is the large cell of the Pacific subtropical belt with the major axis lying east-west. A belt of low pressure parallels the Pacific High along a line from the western Aleutians to the Canadian coast.

WEATHER

Cyclones move rapidly along the northern side of the high, varying greatly in intensity and tending to die out over the continent. Consequently, the northern part of the area is almost continuously in a belt of migratory lows with the accompanying rains, squalls and generally stormy weather with only brief respites between one storm and the next. Storms sometimes move a short distance down the coast before dying out; but throughout the southern part of the ocean area the rainy regimes are short-lived (air mass showers mostly) and the region is marked by fair weather and moderate light winds.

In the western part of the area, between 35^{o} and 45^{o}N., fog and low stratus are frequent since it is here that the warm Tp air is cooled by passage over cooler waters in its northward course. The occurrence of fog is less frequent farther to the north and east chiefly because the higher wind velocities found in this region produce more convection and hence vertical mixing making fog formation less likely.

INDICATIONS

Type A will be recognized by stable conditions and high pressure at Midway, Hawaii and along the California coast with, of course, the winds consistent with the pressure distribution as shown in Plate 7. The Aleutians and southern Alaskan coast and often the Canadian northwest coast will be the scene of a chain of rapidly moving cyclones occluding usually in the Gulf of Alaska and disintegrating along the western mountain ranges.

TREND

The usual shift is to Type B. This is brought about by a deepening and slowing down of the Aleutian Low resulting in a southward swing of the Pacific Polar Front in the western part. The western end of the Pacific High breaks down so that the axis rotates counterclockwise until it is oriented southwest and northeast.

TYPE B (Plate 8)

GENERAL FEATURES

This type is almost as equally prevalent and stable as Type A. It is actually a variation of Type A, and it may be that this type is even more common in winter than Type A; statistics on more than one winter may bring this out. Reed calls this the Southwesterly Type and says that it prevails most of the time and corresponds most nearly to the mean pressure distribution; however, it is felt by the authors that Type A is slightly more persistent. The axis of the High runs northeast and southwest from the vicinity of Hawaii to California. Depressions travel from the vicinity of Midway or slightly north of that island toward the northeast to the continent, finally dying out along the mountain ranges. They may reappear again somewhere to the eastward but seldom intact. However, the appearance of an apparently new low to the eastward of the mountains either in Alberta or the Plateau region is often the precursor of the decadence of one at sea.

WEATHER

Generally good weather prevails in the southeastern section of the North

Pacific, that is, between California and Hawaii. Steady frontal rains, squalls, high winds, low ceilings and overcasts are the most prevalent weather conditions along the trough to the northwestward of the Pacific High, since it is along this trough that the procession of cyclones travels. Still farther to the northwest in the Aleutians and Bering Sea will be found snow, showers and gale winds with brief respites of clearing between successive passages of cold fronts revolving around the Aleutian Low. Only a fresh outburst of Pc air from Alaska in the rear of a cold front will be sufficient to produce any actual clearing, and this will last only a few hours because eventually the colder air will be heated and will pick up more moisture over the warmer water and convective clouds will again form. Almost continual overcast prevails in the central section between Hawaii and Alaska.

INDICATIONS

Type B is characterized by the following: High pressure with steady or rising tendency along the coast of the United States, low pressure along the Aleutian chain extending into the Gulf of Alaska with the usual indications of a series of of cyclones moving northeastward into the southern Alaskan coast, high pressure and the usual trade winds at the Hawaiian Islands, and a low pressure trough at Midway. Upper winds along the coast of British Columbia and western United States will be strong steady westerlies.

TREND

This type shifts back to Type A if the Pacific High is strong and re-establishes itself again in the western part of the area. If, however, the trough deepens in the west so that the Pacific Polar Front is forced still farther south, the Pacific High breaks down completely in the region of Hawaii and only a part of it is left along the west coast of North America with axis north-south. Hawaii is now in the trough and the new distribution has been designated Type C.

TYPE C (Plate 9)

GENERAL FEATURES

This is not a common type but once established seems to persist several days. It develops from Type B as described under that type when the western end of the Pacific High gives way to a series of waves and cyclones which have developed on the Pacific Polar Front after it has been pushed far to the south in the neighborhood of Midway and Hawaii. A trough now exists lying northward from Hawaii all the way into the Bering Sea and the Pacific High has aligned itself north and south in the eastern part of the area. A large part of the eastern North Pacific Ocean is therefore under the influence of low pressure.

WEATHER

No large area enjoys good weather in this type owing to the widespread cyclonic activity, although certain sections have brief intermissions of favorable weather, notably the area just east of Hawaii and small isolated areas in the rear of individual cyclones travelling up along the Polar Front. Fog and low ceilings and low visibilities are the rule in the northward current extending through the central portion of the area.

INDICATIONS

Since the normal conditions described in Types A and B will appear to be about the same along the North American coast and throughout the Aleutian Islands as occur in this type, the clue to the establishment of Type C will be found in a close scrutiny of the immediately previous weather in the vicinity of Midway and Hawaii. The passage of fronts with attendant rains and squalls and wind shifts, falling pressure, and a shift of the wind at Honolulu from the prevailing light easterly to southerly or southwesterly connotes the development of the trough and the breakdown of the western and of the Pacific High and hence the shift to Type C.

TREND

Persistence of the high along the California coast and a marked rising tendency at Hawaii would indicate that the Pacific High is building up again and the trend is back to Type B. This will be accompanied, of course, by an increased cyclonic activity and stronger winds in the Gulf of Alaska.

On the other hand, if the remnant of the Pacific High off the coast breaks down completely so that now the Polar Front lies far to the south of its usual position or the Aleutian Low develops and deepens in a central position in the area, i.e. considerably to the southeast of its mean position, low pressure, strong winds, and generally unfavorable weather prevail throughout the entire eastern North Pacific Ocean and the shift has been designated Type F.

TYPES D_1 and D_2

Both of these types mark a thoroughgoing departure from those which have been discussed. Although each is a transient type, both exercise a profound effect on the weather of the North Pacific. The characteristic feature of Type D is that the major axis of the Pacific High lies in a northwest-southeast direction--a complete breakdown of the normal pressure distribution. The essential difference in appearance between Type D_1 and D_2 is that the former has a deep low off the coast in the vicinity of the Gulf of Alaska, whereas in the latter the low has moved inland or dissipated. Type D_2 is therefore the normal shift of Type D_1.

TYPE D_1 (Plate 10)

GENERAL FEATURES

The stagnation of a very deep low in the vicinity of the Gulf of Alaska results in an outbreak of cold Pc air in the Aleutian Islands. If this air is deep and very cold it will push far to the south until finally it makes up the major part of the Pacific High with the axis extended toward the northwest. Under these circumstances there will normally be a low in the Midway-Hawaii area and we have Type D_1. The cold Pc air in the Aleutian area may or may not be directly connected with the source region; in the early stages it is; in the later stages it is not, owing to the northeastward movement of a new cyclone from the region of the Kamchatkan Peninsula.

WEATHER

Temperatures over the northern part will be the coldest of all the types. Severe icing will be encountered throughout in the lower levels. Gale winds and overcast, snow squalls and rain are the rule; surface visibility, on the other hand, will be generally good except within snow areas. Over the southern part, south of approximately 35°N. weather is generally good. Frequent showers in the Tp air may be expected as usual in the subtropical regions. Reference to the data in Plate 10 shows a lack of significant weather in a number of the squares; this is owing to the fact that the type is not a common one and ship observations are scarce in some sections.

INDICATIONS

Type D_1 is characterized by high pressure with steady or rising tendencies in the Aleutian Islands, a deep occluded low in the Gulf of Alaska, high pressure along the California coast with steady or rising tendencies and a migratory low in the Midway-Hawaii area.

TREND

The normal shift of Type D_1 is to Type D_2. Cold Pc air pouring out of the Arctic or Polar Continental regions finally undergoes a transition to Pp and finally to Transitional Polar Pacific (Npp) Air as described in Part III and the flow is cut off from the north. The low in the Gulf of Alaska moves inland and fills; the axis of the Pacific High is still toward the northwest, but now the high pressure lies right up along the coast of North America. The shift to Type D_2 is now complete.

TYPE D_2 (Plate 11)

GENERAL FEATURES

The whole system is now extremely unstable: the Pacific High is not only out of its usual position and orientation consistent with the general circulation, but the main driving force which maintained the distribution of Type D_1, namely the deep low in the Gulf of Alaska, has disappeared. We find, therefore, in agreement with out expectations, that the type is merely transient and soon gives way to one of the more stable types.

WEATHER

Type D_2 is analogous to Reed's Northwest Type. In this we find fronts moving down the west coast bringing rains and squalls all along the coast, even to Southern California. The whole northwestern part of the area is subjected to frequent and heavy rains, gale winds, and almost constant overcast. The southern part of the area is one of frequent showers, since the air movement consists of convectively unstable Pp air moving generally southward over the warmer waters of the Pacific. Cyclonic activity and frontal movements with attendant rains mark the Midway-Hawaii Area.

INDICATIONS

Northwest winds and high pressure prevail over most of the coast of North America; high pressure exists along the eastern Aleutians and the Alaska Peninsula, although the tendency will usually be downward due to the transiency of the type and the movement of cyclones from the western Aleutians. Careful attention to previous movements in the Midway-Hawaii area should have established the development of low pressure there or slightly to the northward, which, of course, forces the axis of the Pacific High to lie in the northwest-southeast direction.

TREND

If the Aleutian Low moves eastward, thereby forming a trough lying north-south in the western part of the areas, the Pacific High is oriented north-south paralleling the coast of North America. The reversion is therefore to Type C (Plate 9).

The above is hypothetical, since none of the cases investigated developed in this manner; it should be considered, however, as a logical probability. In the cases studied the subtropical high built up in the Hawaiian area, cyclones in that region moved northward toward the Aleutians or even retrograded to the northwest in conformity with the strong southeast winds. On the other hand, the trough in the Gulf of Alaska extended down the coast with some intensification in every case. The picture consisted, therefore, of an extensive trough along the west coast and the Pacific High oriented north-south from Hawaii to Alaska. This distribution we see from Plate 12 is Type E.

TYPE E (Plate 12)

GENERAL FEATURES

Referring to Plate 12 we see the main feature of this type to be the north-south orientation of the Pacific High located in the western part of the area while the west coast of North America and the eastern part of the ocean area is one of low pressure. Type E is not a persistent type although it occurs during a period of fairly stable conditions. It usually forms as a variation of Type A. In other words, the Aleutian Low, instead of being a single center or belt of low pressure, has divided into two distinct centers--one in the Gulf of Alaska and the other in the western Aleutians. The Pacific subtropical High is well established in the southern and western parts of the area and has even pushed north almost to the Alaska Peninsula. Both Type E and Type C have the Pacific High oriented north-south; in Type E it is located in the western part of the area, in Type C the eastern part.

WEATHER

Good weather prevails over a large part of the area in this type. Light winds and only scattered showers will be encountered in the southern part of the area. Mostly light winds and occasional rain characterize the region just southwest of California. As usual, the worst weather is found in the belt along the Aleutian Islands and eastward into the Gulf of Alaska and the Canadian coast. The Aleutians have a high frequency of rain and snow as also the Gulf of Alaska and the Canadian coast; the middle northern section, due to fairly light winds with advection of warmer air from the south is fog covered a large part of the time.

INDICATIONS

The belt of low pressure along the west coast of North America may be formed in two ways: (1) by the succession of a series of cyclones moving down the coast, or (2) by the simultaneous movement of cyclones into the coastal region from both the Aleutian and subtropical regions. The two methods occur with about equal frequency. The first can be easily detected by following the movement of lows and fronts right down the coast; the second is not so readily susceptible of discovery but can usually be determined by falling tendencies along the California coast a day or two in advance of the cyclone. Low pressure and southerly winds prevail in the middle and western Aleutians. High pressure, a steady tendency and the prevailing trades in the Midway-Hawaii area complete the analysis of the type.

TREND

If the migratory low off the California coast moves rapidly inland while at the same time the western center of the Aleutian Low moves eastward, the east-west orientation of the Pacific High is once more established as in Type A. The western Aleutian Low, however, is often of such proportions that it extends far to the south so that the trough encompasses even the Midway area as it moves eastward; meanwhile, the Pacific High moves eastward also into the California coast with its axis extending to the southwest and Type B is reestablished. The normal trend of Type E is therefore to Type A or Type B.

Although Plate 12 shows a deep low in the western Aleutians, this is outside the ocean area under consideration and therefore the existence of this low is not an essential feature of Type E. Should this low be weak or decaying and an outburst of cold Pc air be in progress southward in the Bering Sea, the northern end of the high will be reinforced. Cyclonic development now in the Midway-Hawaii area together with an eastward movement of the Pacific High will result in a northwest-southeast orientation of the axis and therefore a shift to Type D_1.

TYPE F (Plate 13)

GENERAL FEATURES

Although the D Typea mark a breakdown in the general pressure distribution, Type F goes one step further and completely annihilates the whole anticyclonic structure in the eastern North Pacific Ocean. The Pacific High has disappeared from the picture and cyclonic vorticity dominates the entire area. The trade winds at Midway and Hawaii have given way to southerly or southwesterly currents. High pressure usually exists in the western part of the continent; the coast is influenced alternately by Pc air from the continental high and Tp or Pp air from the migratory cyclones in the ocean. The Aleutian Low may be located in the northwest with secondary systems revolving around it as shown in Plate 13, or it may move southeastward, deepen and become centered about centrally in the area so that the only pressure system in the whole area is one gigantic cyclone. The type is not a common one; but once established is several days in dying out since it is the result of a considerable heat unbalance in the general circulation, and the colossal cyclone set up to reestablish the balance must blow itself out.

WEATHER

The worst weather for the ocean area and the greatest extent of unfavorable conditions occur in this Type. Gale winds, snow in the north, heavy rains, almost continual and general overcast and severe icing are the rule. The passage of fronts with the attendant wind shifts, heavy rains, and overcast are felt even as far south as the Hawaiian Islands--in fact, it is in this area that we find considerable cyclogenesis along the cold fronts as explained in Part III.

This type corresponds to Reed's Southerly Type; but his remarks are confined chiefly to the coastal effects: here, it is true, the weather may become clear and dry if the Continental High is strong and deep and extends some distance off the coast. When the trough moves eastward, however, it is marked by warm rains, short-lived southerly blows, and very marked fluctuations in the barometer.

INDICATIONS

The detection of this type is fairly evident from the radical changes in the weather and winds prevailing along the coast simultaneously with those occurring in the Midway-Hawaii area. In both areas the order of the day consists of frontal passages and all their characteristic phenomena: rains, squalls, showers, wind shifts and barometric fluctuations.

TREND

The first signs of the decadence of this type and hence a return to normal conditions are: diminishing cyclonic activity in both the Southern California and and Hawaiian areas; barometric tendencies become steady with slowly rising characteristics; prevailing winds along the California coast return to the northwest while those at Hawaii return to the persistent easterly and northeasterly trades; the weather improves. The Pacific High reestablishes itself along the California-Hawaii axis and the shift is to Type B.

PART V

SUMMARY AND CONCLUSIONS

In such a problem as this we have not attempted to reduce the correlation of weather over the Pacific Ocean with that over the continent to a mathematical formula or some mere arithmetical coefficient or ratio. The correlation is rather empirical or, to be more specific, it is graphical. We are attempting to develop rather a basis for logical thinking by which the meteorologist on the station can construct the most probable and plausible weather pattern. If he is actually within the area, there will be at least one excellent and complete set of observations with all the previous history up to date available, his own. That alone fills a considerable gap, and is closest to his immediate purpose.

An extensive detailed study of synoptic surface maps of the North Pacific Ocean and the North American continent has led to the conclusion that there are no simple pressure or frontal patterns embracing simultaneously the two large regions. A simultaneous graphical correlation between them for surface weather conditions is so complicated, and since the continental weather involves so many extraneous factors such as the Icelandic Low and the Bermuda High, to correlate them successfully would involve a large part of the general circulation of the whole Northern Hemisphere. Any lag correlation would be in the wrong direction, since the continental weather follows the Pacific weather.

A closer network of aerological and pilot balloon stations in the western part of the continent will lead to better analysis of upper wind structure. Since the major air movements of the Pacific are masked at the surface along the coast by mountain and coastal effects, it is felt that the upper air movements along the coast, especially in the 10,000 foot level, may have a definite relationship to the existing pressure field in the eastern North Pacific.

The dominant feature of the weather pattern of the eastern North Pacific is the extensive subtropical anticyclone of the lower latitudes. A type classification of pressure patterns based on the orientation and position of this cell has been evolved. It is felt that these types are simple, distinctive, and few enough in number so that the synoptician can establish the existing type with a minimum of direct observations in the ocean. His success to a large extent will depend on careful analysis, logical sequence, accurate observations in the islands and along the coasts and a knowledge of the typical weather patterns to be expected. We have attempted to present the last of these requirements.

The solution in the absence of direct observations will of necessity be more or less inaccurate, but even an inaccurate map (if treated as such) is far better than a pure white blank. An inventory of the stock on hand available to a forecaster in the Pacific may be summarized as follows:

(1) The average map showing the mean positions of high and low pressure systems and the prevailing air currents in the general circulation.
(2) The typical patterns which we have classified and studied concerning the associated weather and transition into other types.
(3) The kind of weather associated with the various air masses and frontal systems and how the underlying surface affects the air mass above.
(4) The temperature distribution of the ocean.
(5) The weather, pressure and wind distribution, temperature, and tendencies along the coast and island stations giving the clues to the existing type either by direct extrapolation or logical conclusions.
(6) In the case of the meteorologist within the area itself, his own sequence of observations.

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